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1066

THE DESIGN OF FLOATING AID TO NAVIGATION MOORINGS

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1. INTRODUCTION

This guideline combines and replaces the technical content of three existing IALA documents which are withdrawn:

IALA Recommendation E-107 On the Design of Normal Moorings, 1998

IALA Guideline 1024 on Synthetic Moorings, 2001

Practical Notes on the Use of Mooring Chains for Floating Aids to Navigation, 1989'.

Information is provided based on current practices used by IALA members' Authorities in 2009.

2. GENERAL CONSIDERATIONS

In order to ensure the safety of the mariner, lighthouse authorities maintain buoys and light vessels as aids to navigation (AtoN). These floating AtoN are maintained in position by their moorings.

The mooring system must maintain the floating aid in a sufficiently accurate position for it to perform its function as an AtoN.

The mooring consists of a flexible cable connecting the floating AtoN to an anchoring device.

In most cases this Guideline considers buoys connected by a length of mooring cable to a sinker on the seabed. However, the concepts described can equally be applied to large floating aids such as light vessels moored with anchors.

The design of the mooring will depend on:

- The depth of water at the mooring site;
- The buoyancy of the floating aid;
- The seabed conditions at the site;
- The loads imposed on the mooring by the floating aid due to wind, wave action, water flow and ice;
- Loads imposed on the mooring cable by water flow;
- Local conditions that cause wear and corrosion to the mooring;
- Available servicing facilities;
- Required life of the mooring;
- Cost.

3. CHAIN MOORINGS

The most common form of mooring cable is steel chain. The chain will form a catenary between the buoy and the seabed and will be able to absorb considerable amounts of energy. Chain has good wear resistance. With the correct equipment it is easy and safe to handle. Chain can easily be joined with shackles with little reduction in its tensile strength.

Buoy moorings usually consist of open link chain whose size is specified by the bar diameter of the material from which the chain is manufactured. Buoy mooring chain might range from 12.5 to 50 mm. The chain material may be mild steel alloy or a medium carbon, alloy steel may be used where its extra cost can be justified by improved wear resistance.

Stud link chain is not normally used for buoy moorings due to its initial high cost but may be considered where its increased weight, in comparison with open link chain may be an advantage.

However, there are two particular situations where the use of chain is problematic:

- Where very deep moorings are planned, perhaps more than 60 m water depth, a chain mooring may be too heavy for a normal buoy to support the weight of the mooring chain;

In this case synthetic rope may provide a suitable lightweight material for part of the mooring cable. Section 4 provides details of rope moorings.

- Shallow moorings, particularly where breaking waves are encountered may also be problematic for conventional chain moorings.

If breaking waves regularly occur at the buoy site, this would typically be when the wave height was $\frac{1}{4}$ (or more) of the water depth, then each breaking wave will impart considerable energy to the buoy. The mooring chain, which could typically have a length of 7 times the water depth, may not be able to absorb the very high loads generated by a wave swept buoy, resulting in the chain being broken or the sinker dragging from position. One solution to this problem is the use of elastic mooring cable. Section 5 provides details of rubber cord moorings and ANNEX B details the very high loads encountered in moorings where there are breaking waves.

3.1. DESIGN PROCESS FOR A NEW MOORING

To undertake the mooring calculations, it will be necessary to know the physical details of the buoy to be moored and the environmental conditions at the mooring site. Maintenance procedures should also be considered as the buoy may need to provide a safe working platform for servicing personnel.

To refine the calculations, it will also be necessary to know the size and strength of mooring chain that is available, details of sinkers that are available and the capacity of the lifting equipment on the servicing vessels.

3.1.1. DATA REQUIRED

The choice of the class or type of buoy to be used will depend on the AtoN requirements of the particular station. The type or class of buoy to be deployed will depend on the AtoN requirements of the particular stations and will be defined by the combination of:

- the required light intensity;
- the focal plane height,
- the size of daymarks and associated topmarks;
- other AtoN to be carried;
- remote control and monitoring system;
- all associated power systems.

The required AtoN positional accuracy may influence the design of the mooring that will be used. When the mooring loads are calculated it may be found that a larger buoy body than was originally envisaged will be required to maintain sufficient freeboard for daymark requirements or to provide safe working conditions for servicing personnel.

The calculation of loads imposed on the mooring by the wind will require dimensions of the buoy superstructure and daymark.

The calculation of the loads imposed on the mooring by tidal flow or current will require dimensional details of the buoy body and tailtube or skirt.

The calculation of freeboard under maximum mooring load conditions will require the physical dimensions and the displacement of the chosen buoy.

Environmental information for the mooring site will provide details of the worst anticipated wind forces, tidal flow or current and wave heights. Information on the type of bed on which the sinker sits is also needed.

3.1.2. CALCULATION PROCESS

The relevant buoy data and environmental forces can then be used in the 'Transitional Mooring Formulae' to calculate mooring loads, chain size, chain length, sinker size, swinging circle radius and the reserve buoyancy of the buoy.

If the calculated swinging radius does not meet navigational requirements, then the mooring design can be re-calculated with a heavier chain or with the 'Taught Mooring Formulae' so that an acceptable mooring can be achieved. The suitability of the chosen buoy can then be re-assessed by calculating the new reserve buoyancy.

If the swinging radius obtained from the 'Transitional Formulae' (Equation 7) is not a problem, then the 'Slack Mooring Formulae' (Equation 8) may be investigated to see the effects of increasing the chain length to reduce loads on the sinker or possibly reduce the size of the sinker.

3.2. VARIOUS SECTIONS OF THE MOORING

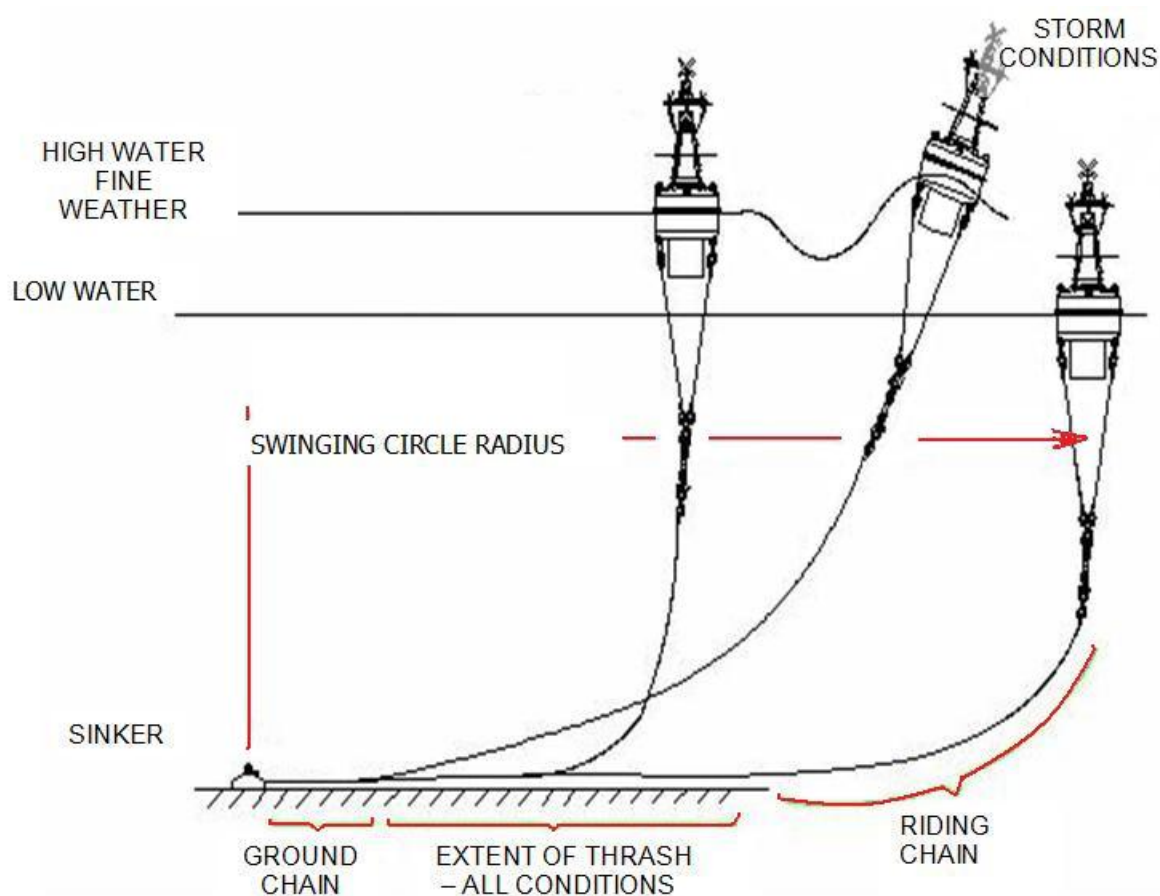


Figure 1 *Buoy Mooring*

A mooring is normally made up of the following parts suitably assembled:

- either a Tail Chain or a Bridle (depending upon the method of securing to the buoy);
- Riding Chain;
- Thrash Chain;

- Ground Chain.

3.2.1. TAIL CHAIN

For buoys with the mooring attached to a single a single mooring eye, this is the length of chain connected to the buoy. It suffers from interlink wear as it absorbs a significant portion of the energy generated by the buoy as it rises and falls following the surface movement of the sea. It also has to absorb the rotational energy of the mooring induced by the buoy rotating around its axis. To limit this effect a stabilising fin can be fitted to the buoy on the opposite side to the mooring eye or at right angles to the axis of the mooring eyes in the case of a bridle mooring. This fin also has the advantage of reducing the oscillation of the buoy in flowing water.

In order to allow buoys with a single mooring attachment point to ride vertically in a variety of water depths and currents, and with differing weights of chain, it is necessary to provide several mooring eyes at different distances from the buoy axis.

In the case of a tail tube buoy the tail chain should be increased in size to allow for extra wear where the chain rubs against the tube. To lessen this chafe some Services attach a wooden rubbing band around the bottom of the tube.

3.2.2. BRIDLE

A bridle comprises two equal lengths of chain shackled to the buoy on opposite sides. The two chains are joined below the buoy by means of either a triangular or circular link, or a shackled assembly.

Below this point there can be a swivel or a direct connection to the next section of chain.

The use of a bridle enables buoys to ride vertically without needing several mooring eyes in different positions to cope with different conditions of water flow or different weights of moorings.

3.2.3. RIDING CHAIN (RISER)

The Riding Chain or Riser connects the bridle or tail chain to the thrash chain. It can vary in chain size (bar diameter) and length depending on the buoyancy of the aid, the depth of water and expected forces on the chain. The chain must be of sufficient strength to recover the sinker. Usually chains are delivered in standard lengths and joined together with shackles.

This section of the mooring remains suspended beneath the buoy and is not subjected to wear on the seabed. Hence this section of the mooring may utilise synthetic rope where there are special requirements for a lightweight mooring, usually in deep water situations, or a rubber cord in very shallow moorings where large amounts of wave energy must be absorbed. Both synthetic rope and rubber cord are discussed later in this Guideline.

3.2.4. THRASH CHAIN

The Thrash Chain is the part of the mooring lying on or near the seabed, connecting the riding chain to the ground chain. Due to tidal influences (rise, fall and current) and the sea and wind conditions the thrash chain continually moves on the seabed. In the case of a sandy bottom severe wear can be expected in this area of the mooring.

It is usual to renew this part of the mooring first, either with new chain or by exchanging with a length of chain from elsewhere in the mooring.

In some cases, the chain size (diameter) is increased in this section to offset the wear.

3.2.5. GROUND CHAIN

The Ground Chain lies on the seabed between the thrash chain and the sinker, and sometimes becomes embedded.

This section of the mooring may be increased in length or a larger chain size used to reduce loads transmitted to the sinker.

The ground chain, the sinker and the resilience of the other parts of the mooring keep the buoy in position.

Note: For small to moderate sized moorings the riding chain, ground chain and thrash chain may be formed by one continuous length of chain. However, these terms are still used to identify the various sections of the mooring.

3.2.6. SWINGING RADIUS

The swinging radius is the radius of the circular movement of the buoy about the position of the sinker at low water. Ice may increase the swinging radius as the increased load imposed by the ice may pull the chain into a straight line.

In tidal or river conditions, the excursion of the buoy will be in the direction of water flow

3.2.7. SINKER

The sinker usually provides the attachment of the mooring to the seabed. Sinkers have the advantage that they can resist loads from all directions. Anchors may be used when the mooring load is always in one direction. An anchor can provide considerably more resistance than a sinker of the same weight but only when the anchor is correctly buried in the sea or river bed.

3.3. MOORING DESIGN

This section provides a methodology to calculate the dimensions of a chain mooring and the weight of sinker required. The process requires knowledge of the environmental conditions at the mooring site, details of the local wave regime and the dimensions of the buoy that will be moored. Details of the type of seabed will be needed to establish the required weight of the sinker.

Navigational requirements regarding an acceptable swinging radius for the buoy may require further refinement of the mooring design.

At sites where damage to flora and fauna on the seabed is of concern then the mooring may have to be designed so that there is no ground chain sweeping the seabed.

In areas such as the Baltic, where there is very little tidal range, tensioned moorings are often employed. These connect the buoy directly to the sinker with a line of the minimum possible length so that the tension in the mooring line maintains the buoy in an upright position.

Information gained from practical experience with other buoys in the proposed mooring area will prove valuable in verifying the results of the calculations. The calculations make the assumptions that the:

- buoy axis is vertical under the most common conditions of current and wind;
- reserve buoyancy of the fully equipped buoy is sufficient under the worst conditions of wind and tide;
- drag due to water flow on the mooring chain is not significant in currents less than 5 knots (kn) and water depths less than 40 m. Additional calculations will be required at deeper sites and for sites with fast currents.

3.3.1. MOORING TYPES

Details are provided for the three main types of mooring:

- Transitional Mooring;
- Slack Mooring;
- Taut Mooring.

The following text describes these three types of moorings and how the moorings loads may be calculated.

3.3.1.1. Transitional Mooring

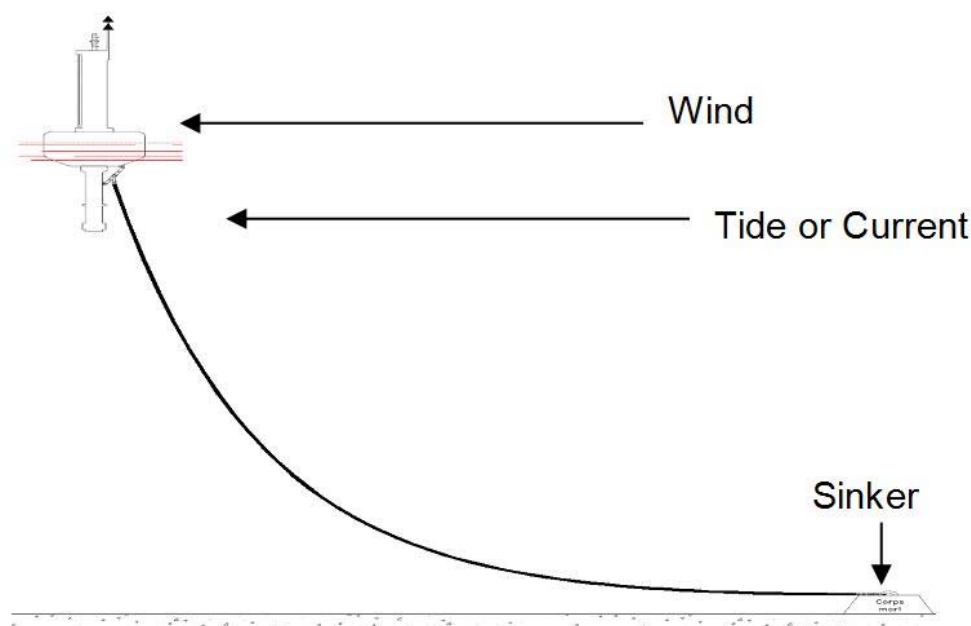


Figure 2 *Transitional Mooring*

The transitional mooring (see Figure 2) is the ideal mooring state where the mooring chain catenary meets the seabed tangentially exactly at the sinker when there are the maximum wind and tide (or current) loads on the buoy. The mooring loads will be transferred horizontally to the sinker, which will be working as effectively as possible.

3.3.1.1.1 Transitional moorings Loads

The loads caused by wind and tide on the buoy are calculated from the following formulae:

$$T_{ho} = F_w + F_d$$

Equation 1 *Transitional loads caused by wind and tide*

Where

T_{ho} is the the horizontal load caused by wind and tide in Newtons (N)

F_w is the maximum wind load on the buoy (N)

F_d is the maximum tide (or current) load on the buoy (N)

$$F_w = \frac{1}{2} \rho_a V_w^2 A C_w$$

Equation 2 *Maximum wind load on a buoy*

Where:

ρ_a is the unit mass of air in kilograms per cubic metre (kg/m³)

V_w is the maximum wind velocity in metres per second (m/s)

A is the cross sectional area of the parts of the buoy exposed to the wind in square metres (m²)

C_w is the aerodynamic drag coefficient of the relevant parts of the buoy exposed to wind loads.

Typical values for CW are as follows:

Cylinder	0.3 to 0.4
Flat Plate	1.0
Lattice construction (angles)	1.2
Lattice construction (tubes)	0.3 to 0.4

$$F_d = \frac{1}{2} \rho_o V_w^2 A C_d$$

Equation 3 Maximum tide (or current) load on a buoy

Where

ρ_o is the unit mass of sea water in kg/m³

S is the cross sectional area of the immersed areas of the buoy in m²

V is the maximum velocity of the current or tide in m/s

C_d is the hydrodynamic drag coefficient of the various immersed sections of the buoy

Typical values for C_d are 0.55-0.65 (without fouling) depending on buoy type. An example is shown in ANNEX A, where trials have established a drag coefficient of 0.55 for a conventional skirt type buoy.

3.3.1.1.2 Chain Size for transitional mooring

The practical size of the chain can then be ascertained by trying the strength and immersed weight of various sizes of commercially available chain in the following formulae

$$R_c \geq 5(pgH + T_{ho})$$

Equation 4 Practical chain size for a transitional mooring

Where

R_c is the proof load of the chain (N)

p is the linear immersed mass of the chain (mass minus the buoyancy of the chain) in kilograms per metre (kg/m)

H is the maximum water depth at the station in metres. This should include wave height.

T_{ho} is the horizontal load imposed by the buoy - this is equal to the horizontal mooring load at the sinker (N)

g is the acceleration due to gravity in metres per second squared (m/s²)

The safety factor of 5 takes account of the continual cyclic load and wave effects that the chain is subjected to by the motion of the buoy.

This calculation will provide a guide to the size of chain required and the following formulae can then be used to establish the required length of the mooring chain.

3.3.1.1.3 Chain Length for transitional moorings

$$L = \sqrt{H \left(H + \frac{2T_{ho}}{pg} \right)}$$

Equation 5 Chain length for transitional moorings

3.3.1.1.4 Reserve Buoyancy for transitional moorings

Sufficient reserve buoyancy will be required to provide an adequate daymark, to ensure that the body will not be submerged by normal waves and to provide a safe working platform if it is required for servicing personnel to work on the buoy while it is afloat.

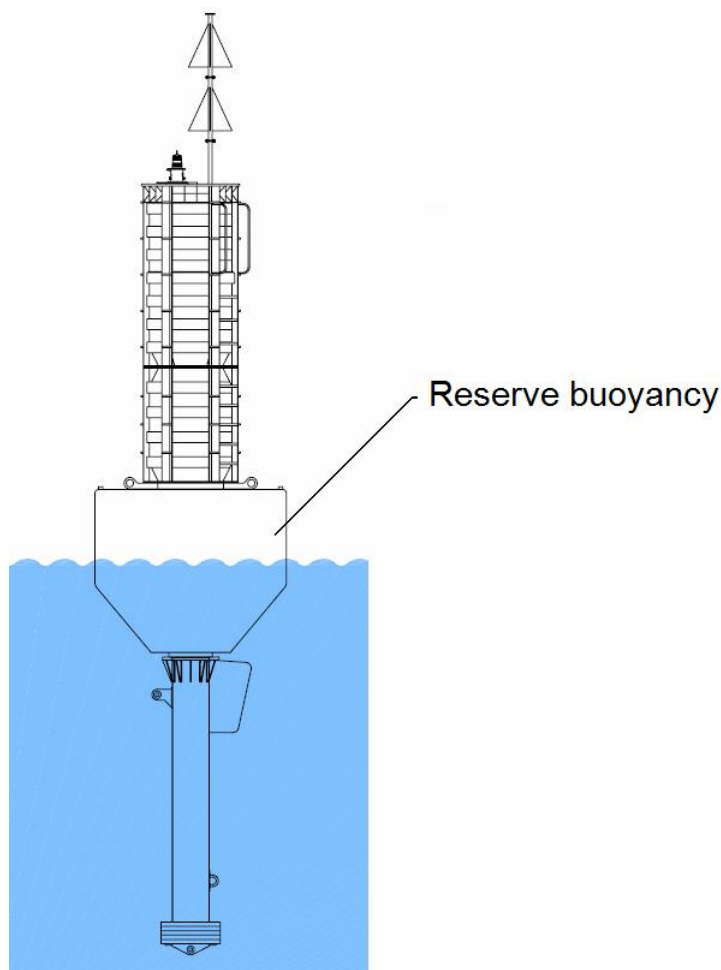


Figure 3 *Reserve Buoyancy*

The load imposed on the buoy can then be calculated to see if the proposed buoy will have sufficient reserve buoyancy.

$$R_b = U - \frac{M_b + m_c L}{\rho_w}$$

Equation 6 *Load imposed on a buoy*

Where

R_b is the volume of reserve buoyancy in cubic metres (m³)

U is the total volume of the float (m³)

M_b is the mass of the buoy (kg)

m_c is the linear immersed mass of the chain (kg/m)

L is the suspended length of the mooring (m)

ρ_w is the density of water (kg/m³)

3.3.1.1.5 Swinging Radius for transitional mooring

The swinging radius (see Figure 1) of the mooring can then be calculated from the formulae.

$$R_m = L - \sqrt{H_m \left(H_m + \frac{2T_{ho}}{pg} \right) + \frac{2T_{ho}}{pg} \cosh^{-1} \left(H_m + \frac{pg}{T_{ho}} + 1 \right)}$$

Equation 7 Swinging radius for a transitional mooring

Where:

R_m is the maximum swinging radius in metres (m)

L is the total length of the mooring (m)

H_m is the minimum depth of the station (m)

g is the acceleration due to gravity (m/s^2)

T_{ho} is the horizontal mooring tension at the connection with the sinker (N)

ρ is the linear immersed mass of the chain (mass minus the buoyancy in mass of the chain) (kg/m)

It will then be possible to see if the designed mooring meets navigational and operational requirements.

Will the swinging radius be acceptable? If the buoy is marking a navigable channel, then the swinging radius may need to be reduced. This can be achieved by using a larger size of mooring chain. The effect of this can be investigated by re-calculating the mooring design with increasingly larger sizes of chain.

If further reduction of the swinging circle radius is required, then the 'Taught Mooring' may be considered. (See section 3.3.1.3)

The reserve buoyancy of the buoy must also be monitored as larger sizes of chain are considered.

Consideration may be given to the use of a resilient beacon, a piled beacon or a two legged mooring if precision marking is required.

3.3.1.2. Slack moorings

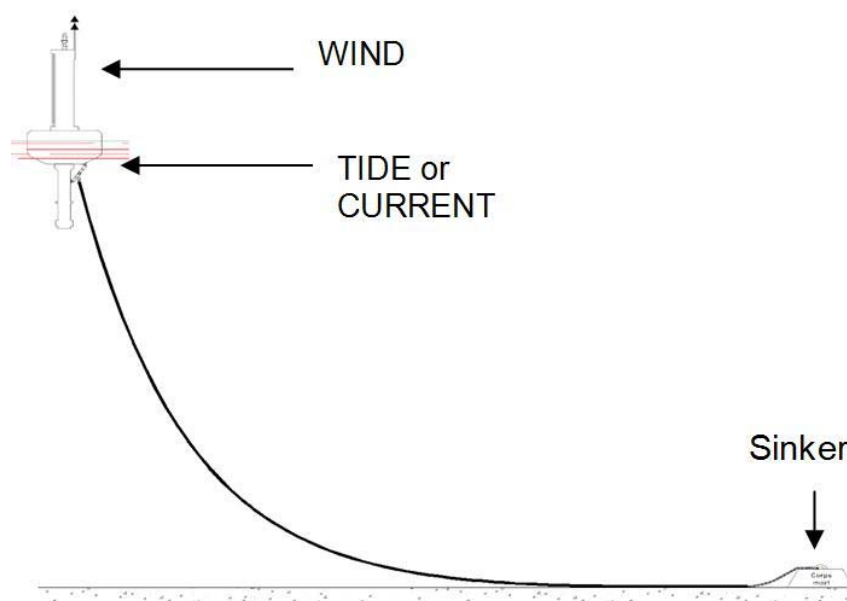


Figure 4 Slack Mooring

In practice, this is the most common form of mooring.

Slack moorings have chain permanently on the seabed. When the loading on the buoy is at its maximum the mooring chain catenary will meet the seabed some way from the sinker. The chain on the seabed increases the security of the mooring or may be used to reduce the size of the sinker (See Figure 4)

3.3.1.2.1 Ground Chain Resistance for slack mooring

The following formulae evaluate the effective increase in mass that the ground chain provides to the sinker.

$$M_{gained} = m_c L_g \frac{\tan \phi}{K}$$

Equation 8 *Effective increase in mass that the ground chain provides to the sinker*

Where

M_{gained} is the effective increase of sinker mass provided by the ground chain (kg)

M_c is the linear immersed mass of the chain (mass minus the buoyancy of the chain) (kg/m)

K is a safety coefficient (generally taken equal to 1.5)

ϕ is the internal friction angle of the sea bed (this depends on the type of soil at the station), 45° (0,7855 in radian) is a practical approximation that can be used in most cases. Chalk and some gravel bottoms provide a lower friction angle.

L_g is the length of the ground mooring that lies on the seabed (m)

This mooring arrangement is often used in open waters where the consequently large swinging radius of the buoy is acceptable. The length of ground chain provides energy absorbing capabilities in extreme weather conditions.

Another consideration may be that the weight of the sinker may be reduced by using a long ground chain if the required sinker weight for the transitional mooring is greater than the servicing vessel's lifting capacity.

3.3.1.3. Taut Mooring

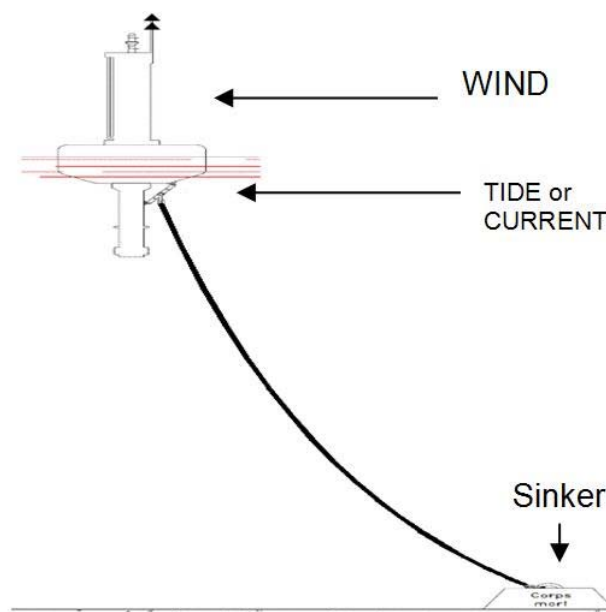


Figure 5 *Taut mooring*

If the swinging radius derived from the initial mooring design is too large for navigational requirements, for example the edges of dredged channels often require very precise marking, then a Taut Mooring may have to be considered.

Similar design constraints will apply if the local seabed is an important marine ecosystem. It may then be necessary to design a taut mooring such that most of the mooring chain is suspended from the buoy. Any damage that the mooring chain causes to the seabed will then be minimised.

In areas with a rough rocky seabed there is a chance of the mooring chain catching on outcrops of rock. If the mooring is designed as a transitional or a slack mooring then it is possible that part of the chain on the seabed will catch on a rock and effectively shorten the mooring. The loads on the chain and the buoy will then be increased, possibly to the point of failure. These problems can be minimised by designing the mooring as a taut mooring.

The taut mooring (see Figure 5) has the mooring chain meeting the sinker at an angle when the maximum wind and tide loads are acting on the buoy. There will then be a vertical component of the mooring load applied to the sinker. This will require a larger sinker to maintain the buoy on station.

The chain size and length and sinker weight may now be calculated to meet the swinging radius requirements for the particular buoy station. A check must again be made to ensure that the buoy has sufficient buoyancy to support this mooring in the worst environmental conditions.

The following formulae are provided for this mooring calculation.

3.3.1.3.1 Taut Mooring Loads

For the vertical mooring load on the sinker

$$T_{vo} = \frac{pgH \sqrt{4T_{ho}^2 + (pgL)^2 - (pgH)^2}}{2\sqrt{(pgL)^2 - (pgH)^2}} - \frac{pgL}{2}$$

Equation 9 *Vertical mooring load on a sinker*

Where:

T_{vo} is the vertical mooring tension at the connection with the sinker (N)

T_{ho} is the horizontal mooring tension at the connection with the sinker (N) (equal to the horizontal mooring tension at the connection with the buoy as the horizontal tension is integrally transmitted along the mooring)

ρ is the linear immersed mass of the chain (mass minus the buoyancy of the chain) (kg/m)

H is the maximum depth of water, including wave height (m)

L is the length of the mooring (m)

3.3.1.3.2 Chain Size for taut moorings

For the chain strength:

$$R_c \geq 5 \left(pgH + \sqrt{T_{ho}^2 + T_{vo}^2} \right)$$

Equation 10 *Practical chain size for a transitional mooring*

Where:

R_c is the proof load of the chain (N)

ρ is the linear immersed mass of the chain (mass minus the buoyancy in mass of the chain) (kg/m)

H is the maximum water depth at the station, including wave height (m)

T_{ho} is the horizontal load imposed by the buoy, which is equal to the horizontal mooring load at the sinker (N)

T_{vo} is the vertical load imposed by the weight (in water) of the chain plus the vertical load on the sinker (N)

g is the acceleration due to gravity (m/s²)

The safety factor of 5 takes account of the continual cyclic load that the chain is subjected to.

3.3.1.3.3 Reserve Buoyancy for taut moorings

For the reserve buoyancy:

$$R_b = U - \frac{M_b + M_c L + T_{vo}}{\rho_w}$$

Equation 11 Reserve buoyancy

Where

R_b is the volume of reserve buoyancy in cubic metres (m³)

U is the total volume of the float (m³)

M_b is the mass of the buoy (kg)

m_c is the linear immersed mass of the chain (mass minus the buoyancy of the chain) (kg/m)

L stands for the suspended length of the mooring (m)

T_{vo} is the vertical mooring tension at the connection with the sinker (N)

g is the acceleration due to gravity (m/s²)

ρ_w is the density of water (Kg/m³) (taken equal to 1024 Kg/m³ for salt water)

3.3.1.3.4 Swinging Radius for taut mooring

For the taut mooring swinging radius:

Note: maximum swinging radius will occur at the lowest water level. Check that the mooring remains taut in these conditions.

$$R_m = \frac{T_{ho}}{pg} \cosh^{-1} \left(\frac{pgH_m}{T_{ho}} + \frac{\sqrt{T_{ho}^2 + T_{vo}^2}}{T_{ho}} \right) - \frac{T_{ho}}{pg} \sinh^{-1} \left(\frac{T_{vo}}{T_{ho}} \right)$$

Equation 12 Taut mooring swinging radius

Where:

R_m is the swinging radius (m)

H_m is the minimum depth of the station (m)

T_{ho} is the horizontal mooring tension at the connection with the sinker buoy (N)

T_{vo} is the vertical mooring tension at the connection with the sinker buoy (N), calculated with the formulation (5) at the minimum depth, Mass of the chain

p is the immersed linear mass of the chain (mass minus the buoyancy of the chain) (kg/m)

3.3.2. SINKER WEIGHT

A very simple way to design the sinker weight consist in taking only into account the effect of the friction with the sea bottom (the 'burying' and the 'rock stopping' effects are not taken into account).

Under these hypotheses, the minimum weight of the sinker is provided by the formula.

$$M \geq K \frac{T_{ho} \delta}{g(\delta - \rho_w) \tan \phi} + \frac{T_{vo}}{g}$$

Equation 13 Minimum weight of sinker

Where:

M is the mass of the sinker (kg)

K is a safety coefficient (generally taken equal to 1.5)

T_{ho} is the horizontal mooring tension at the connection with the sinker (N)

T_{vo} is the vertical mooring tension at the connection with the sinker (N)

δ is the mean density of the sinker (kg/m^3) (generally taken equal to 2400 kg/m^3 for a reinforced concrete sinker and 7800 kg/m^3 for cast iron)

g is the acceleration due to gravity (m/s^2)

ρ_w is the density of water (kg/m^3) (taken equal to 1024 kg/m^3 for salt water)

ϕ is the internal friction angle of the sea bed (it depends on the type of soil at the station), 45° (0.7855 in radian) is a practical approximation that can be used in most cases. Chalk and some gravel bottoms may provide a lower friction angle. Relevant information can be found in civil engineering textbooks.

3.3.2.1. Sinker Weight for Transitional and Slack Moorings

In the case of a Transitional or a Slack mooring, the vertical tension of the mooring at the connection with the sinker is equal to zero, and consequently, the relationship above can be simplified:

$$M \geq K \frac{T_{ho} \delta}{g(\delta - \rho_w) \tan \phi}$$

Equation 14 *Sinker weight for transitional and slack moorings*

3.3.3. BURIED SINKERS

It must be noted that in-service sinkers often become buried in the sand or mud on the seabed. In order to recover the sinker, the servicing vessel will then have to haul up the mooring chain and break the sinker out of the seabed.

The following empirical formulae provide an estimate of the maximum load that may be encountered:

$$H_c = 2M \frac{\delta - \rho_w}{\delta} + H_m m_c$$

Equation 15 *Estimate of the maximum load that may be encountered with a buried sinker*

Where:

H_c is the hauling capacity of the servicing boat (likely a buoy tender) (kg)

M is the mass of the sinker (kg)

δ is the mean density of the sinker (kg/m^3) (generally taken as 2400 kg/m^3 for a reinforced concrete sinker and 7800 kg/m^3 for cast iron)

ρ_w is the density of water (kg/m^3) (taken equal to 1024 kg/m^3 for salt water)

H_m is the depth of water when the mooring is lifted (m) (generally, it is the maximum depth of the site that is taken into account)

m_c is the immersed linear mass of the chain (mass minus the buoyancy of the chain) (kg/m)

See ANNEX C: Example of mooring calculation for one of the French Service's standard buoys.

3.4. CHAIN MOORING COMPONENTS

The components used to assemble a mooring system are:

- Chain;
- Shackles;
- Swivels;
- Sinkers or anchors.

It is important that all components (including sinker and anchor eyes) are manufactured from the same quality material to minimize electrolytic corrosion and wear.

3.4.1. CHAIN

Chain size is defined by the bar diameter of the chain links. However various lengths of chain links have been established depending on local manufacturing processes, national standards and operational requirements.

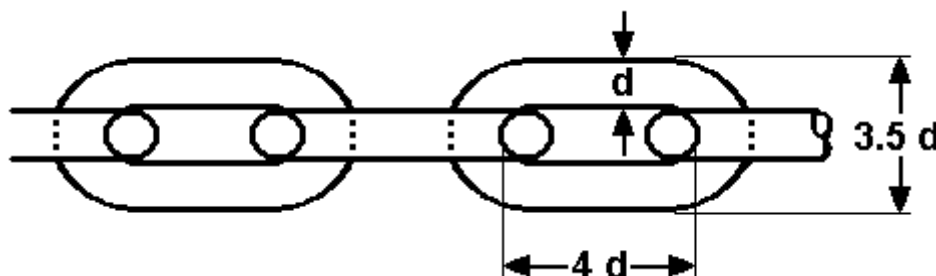


Figure 6 4d chain

The proportions of the chain link are described as the ratio between the bar diameter and the inside length of the chain link.

Each Service should define a dimensional ratio in consultation with the supplier and manufacturer that will allow the use of their standard shackles and other chain connections.

Examples of ratios currently in use are:

- France 3d, 4d and 5d;
- UK 4d;
- Netherlands 5d;
- Germany 9d.

The shorter link chain requires more links per length. It is heavier and therefore can be more expensive, but it is easier to handle with a winch. However, the links may not be of sufficient size to accept a joining shackle and enlarged end links may be required on each length of chain.

The longer link chain may not require an enlarged end link in order to insert a joining shackle. Long lengths of chain can then be cut to the required length for a particular mooring. It is easier to handle with a hook and permits one size of hook on the hoisting equipment to be used for several sizes of chain. There is also less risk of 'knotting'.

Consideration must be given to the chain handling method, and particularly the dimensions of the servicing vessels' chain handling capstan if different link lengths are to be used.

3.4.1.1. Material used in the manufacture of chain

Chain is manufactured from grades of steel that are suitable for forging into the shape of the link and also capable of being reliably welded. A variety of steels fall into these categories and provide different combinations of strength, hardness, wear resistance and cost. A particular steel may be slow to wear but not be resistant to corrosion or vice versa. Generally, a compromise must be found in the quality of material that will minimise both wear and corrosion at an acceptable cost

Steels with a high carbon content (0.2%) and high manganese content (1.5%) have proved to be very effective for buoy mooring chain. It should be noted that Lloyd's U grades and German DIN grades are based on the chain strength and do not specify a particular grade of steel. The wearing performance of the chain will therefore not be defined. It is recommended that national authorities should specify the steel used in the manufacture of their chain.

Chains may be heat treated to reduce stress concentrations caused by the forming and welding processes and to generally improve the strength of the chain. However, some Authorities have found non-heat treated chain manufactured from low-carbon steel to be acceptable in use and hence more cost effective.

Table 1 provides an example of the steel used by the Netherlands Authority. This is an acceptable high performance chain mooring steel. The chain in this example is heat treated by quenching and tempering.

Table 1 Typical Chain Steel

Material	Min %	Max %
Aluminium	0.015	0.025
Carbon	0.25	0.26
Chromium	0.20	0.30
Copper	-	-
Manganese	1.40	1.60
Molybdenum	0.10	1.20
Nickel	0.20	0.30
Phosphorus	-	0.02
Silicon	0.20	0.35
Sulphur	-	0.02
Vanadium	0.08	0.12

3.4.1.2. Chain finish

Some authorities specify a protective coating to limit corrosion while the chain is stored awaiting deployment.

3.4.1.3. Specifications and Standardisation

A specification should include details of the material from which the chain is to be made, the heat treatment, the finished dimensions of the chain and the mechanical properties of the material and the finished chain. Details of test procedures and certification processes will be included to enable the purchaser to prove that the chain meets the specification. It should also include means of identification of individual chain lengths.

The use of the specification will enable an Authority to purchase chain of a standard quality that will perform in a consistent manner when in service.

3.4.2. BRIDLES

The bridle consists of two equal lengths of chain shackled to the buoy's mooring eyes. Some bridles are designed of sufficient length to pass beneath the skirt or tailtube of the buoy. Other bridles are shorter, and are designed to rest against the tailtube and thus provide additional stability to the buoy. When these shorter bridles are used, a chafing block is normally installed on the tailtube to prevent abrasion damage from the bridle.

The 'legs' of the bridle can be joined together in several ways: by a circular link, triangular link, 'cat face' (a triangular plate with three holes), or a single shackle. From the centre connection, the bridle can be joined directly to the mooring chain, or a swivel may be incorporated.

Traditionally, the components are assembled as part of the chain manufacturing process, with the connecting links being forged to shape and welded. The bridle assembly can then be tested and certified in a similar way to the chain itself. If the bridle components are instead assembled locally with shackles, the complete bridle cannot then be tested. Also, depending on the proportions of the chain links, it may not be possible to use a shackle that is equal in strength to the chain itself. Shackled connections are generally considered to be less reliable than fully tested chain links.

3.4.3. SHACKLES

The shackle is the most widely used device for attaching the mooring to the buoy, and joining the other components of the mooring together.

The strength of the shackle should be at least equal that of the chain which it is joining. Thus, the diameter of the shackle bow will likely be greater than the size of chain which it is joining together. In this case, it may be necessary for the chain to have enlarged end links to accommodate the joining shackles.

Confusingly, the size of a shackle may refer to the size of the chain which it fits or it may refer to the diameter of the shackle pin. Local standards must be consulted to ensure the correct definition of sizes.

The types of shackles/connectors in use are:

- Forelock shackles;
- Clenching shackles;
- Bolt shackles;
- Screw Pin shackles;
- Kenter shackle;
- Quick Release Link.

3.4.3.1. Forelock Shackles

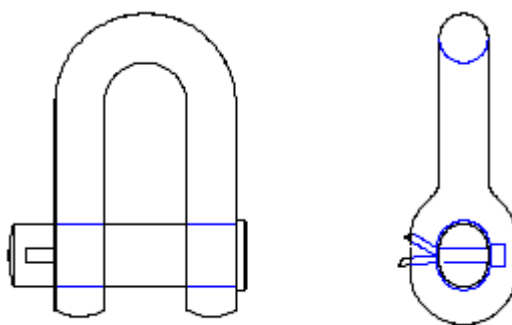


Figure 7 Forelock shackle with oval pin

The forelock shackle is a very reliable type and it is easy to use. It can be manufactured in size and shape to suit the components that it is connecting and it has a forelock to secure the pin. This has the advantage that in use the forelock is the least stressed component. However, these shackles should not be used in the thrash zone of a mooring. This is because the movement of the chain could cause the forelock to come loose or wear away.

The pin can be round or oval in cross section. The round pin is cheaper to manufacture but it has the disadvantage that in service it can rotate, thus wearing the forelock and eyes of the shackle. The more expensive oval pin overcomes this disadvantage.

3.4.3.2. Clenching Shackles ("Heat and Beat" - United States)

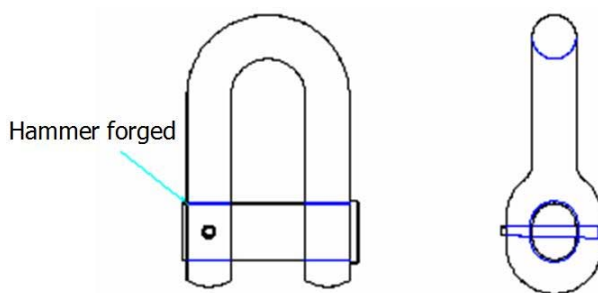


Figure 8 *Clenching shackle with oval pin*

3.4.3.3. Bolt Shackles

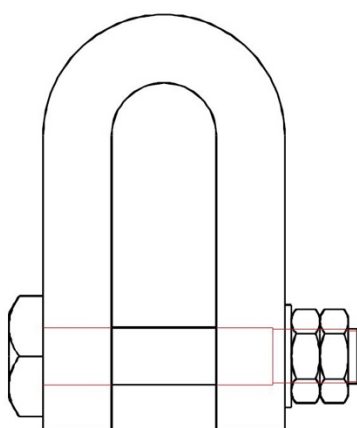


Figure 9 *Bolt shackle*

The bolt shackle has a round pin secured by one or two nuts. If only one nut is used, then a cotter pin or a split pin must secure the nut. Authorities who choose to use these shackles may find it prudent to weld the nuts and pins in place.

A disadvantage of this shackle is that the round pin can rotate in the eyes of the shackle resulting in rapid wear. In addition, the nut can come loose in service through abrasion against the seabed or active movement of the mooring chain. For these reasons, the bolt shackle is not recommended for use in the thrash zone.

3.4.3.4. Screw Pin Shackles

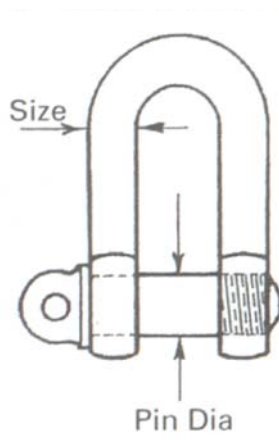


Figure 10 *Screw pin*

These should not be used in permanent moorings or in the thrash zone, as any rotation of the shackle pin will result in failure of the shackle.

3.4.3.5. Kenter Shackles

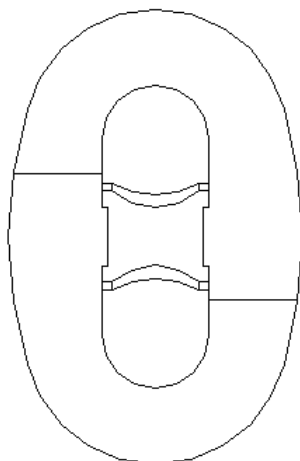


Figure 11 *Kenter Shackle*

These are commonly used in ship moorings but are not usually used for permanent moorings where long term corrosion and wear will result in the shackle literally falling apart.

3.4.3.6. Quick release links

Many types are available, one of which is illustrated below. These may be used close to the buoy where the mooring is always in tension if there is a requirement to regularly or quickly disconnect the mooring.

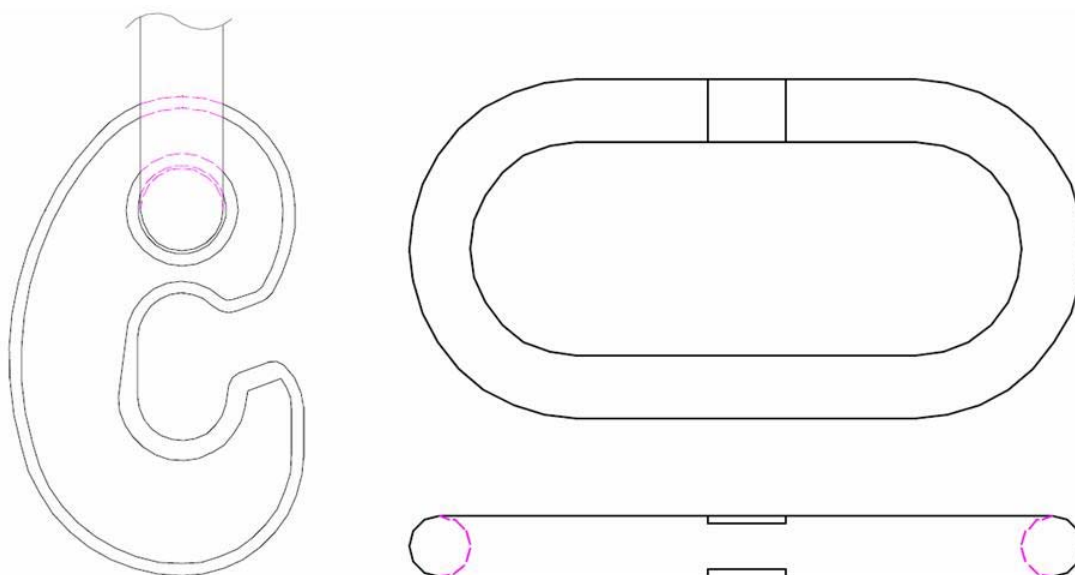


Figure 12 *G hook and connecting link*

3.4.4. SWIVELS

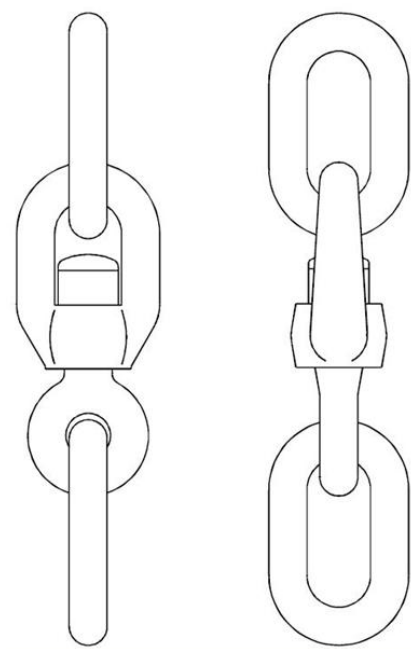


Figure 13 Swivel

A swivel permits two lengths of chain to be joined without transmitting a twisting motion (torque) from one length to the other.

Due to the rotation of a buoy around its axis, a twisting action is applied to the chain. This may result in the chain knotting, ultimately affecting the riding quality of the buoy and the effectiveness of the mooring. In such a case one or more swivels can be inserted into the mooring. Usually a swivel is placed between the Tail Chain or Bridle and the Riding Chain.

Experience shows that the quality of swivels requires careful monitoring to ensure that their strength and working life matches the other components of the mooring. They should be made of the same material as the chain.

Swivels may seize due to corrosion, wear and/or marine growth. If severe marine growth occurs, regular inspection and cleaning is recommended.

3.4.5. SINKERS

Experience has shown that sinkers are adequate to keep buoys in their assigned positions. They do not provide the resistance or holding power of anchors of the same weight but have the great advantage that they will provide the same resistance irrespective of the direction that the mooring load is applied.

Sinkers may be made of concrete, cast iron, rock or bundles of used chain.

Whilst most Authorities use sinkers, in some cases anchors are necessary to resist high mooring loads. For example LANBYS (LNB) on exposed stations use a combination of sinkers and anchors. Floating aids in rivers where the current direction is constant may utilise anchors. The anchor will remain buried in the river bed as the load from the buoy will always come from one direction.

The effective sinker weight will be equal to the weight of the sinker in air minus the weight of the water displacement.

3.4.5.1. Concrete sinkers

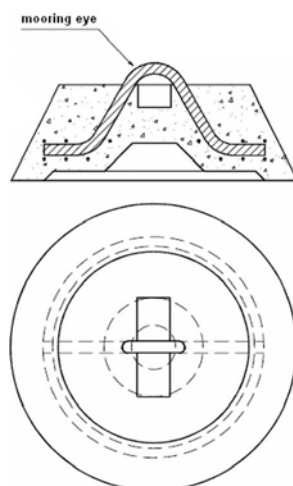


Figure 14 Concrete sinker

These are of moderate cost and widely used. They are manufactured by casting concrete into a suitably shaped mould with a metal eye for attachment of the mooring chain cast in place. Concrete sinkers can be made with local labour using local materials. However, they are considerably larger than cast iron sinkers of the same submerged weight and thus take up valuable storage space in the depot or on the buoy tender's deck. Care must be taken in all aspects of their manufacture so that they do not disintegrate or allow the mooring eye to pull out. The quality of the concrete must be carefully monitored to ensure it is of the specified density. The density is often improved by including steel reinforcement or scrap chain in the concrete. Hematite may also be used as an aggregate to increase the density of the concrete.

The metal eye of the sinker is typically made of a medium-carbon steel with good abrasion resistance. Steel reinforcing bar ('rebar') is not generally suitable for mooring eyes.

See ANNEX D for manufacturing details of sinkers used by American, English and French services.

3.4.5.2. Rock sinkers

An alternative sinker can be made by fixing a mooring eye in a piece of rock, or large stone. This may be effective if there is a local supply of dense stone in suitable sizes. However, it is very difficult to assess the condition of an individual rock and it can break in service.

3.4.5.3. Cast iron sinkers

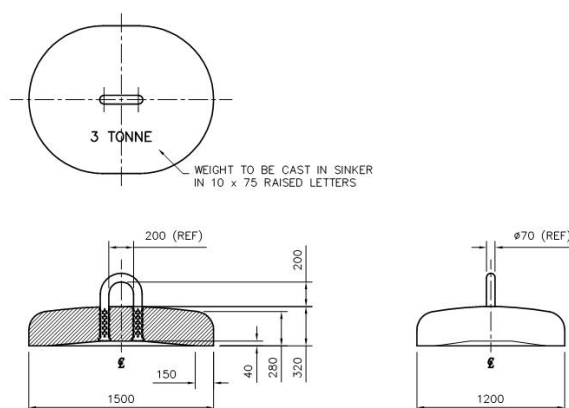


Figure 15 Trinity House 3 tonne cast iron sinker

The most expensive but the most durable and effective sinkers are made of cast iron. Their density compared with concrete is approximately in the ratio of 3:1.

Cast iron sinkers are robust and the repair or replacement of the mooring eye is possible.

If a mooring is prone to sanding in, a cast iron sinker will be easier to extricate than a concrete sinker because its physical size is smaller. However, if lost its replacement will be more expensive than a concrete sinker.

There are many designs and shapes of cast iron sinkers. It may be cost effective to use scrap cast iron if suitably dimensioned pieces are available. See ANNEX D for dimensions of various sizes of cast iron sinkers.

3.4.5.4. Fixed Moorings

Mooring points fixed to the sea or river bed may be used in particular circumstances. Piles can be driven into the sea bed to form a mooring attachment and mooring eyes can be fixed directly to river beds that are formed of solid rock.

3.5. MOORING WEAR AND CORROSION

The two main factors which influence the service life of a mooring system are wear and corrosion. These two factors are interactive since the products of corrosion rapidly accelerate wear.

The performance of the mooring chain depends upon the choice of the correct steel specification and must take into account the acceptable amount of wear within the working life of the mooring.

3.5.1. CORROSION

Rust, electrolytic action and pollution may reduce the normal life of a mooring line. Rust, which is due to oxidation, occurs both ashore and at sea. Electrolytic action results from a potential difference between components of a mooring. This is caused by using dissimilar metals in the same mooring immersed in a common electrolyte, in this case water. It shows as pitting near and in the welds of chain links and in the chain each side of connecting shackles, over a length, of about 1 2 m. Electrolytic action can be significantly reduced by making the buoy body and all the metallic components of the mooring from the same or very similar grades of steel. Polluted waters also have an influence on the extent of pitting corrosion. It is mainly observed in the riding part of the mooring chain and has occasionally been observed in the skirts of steel buoys.

3.5.2. WEAR

The extent to which wear occurs mainly depends on the quality of the materials from which the mooring is made. Wear is also affected by local environmental conditions, in particular:

- Type of seabed;
- Amount of sand transport in the water;
- Tidal conditions;
- Depth of water;
- Sheltered or open waters;
- Weather conditions.

The mooring cannot change these conditions but can only react to them.

A reduction in bar diameter will be observed at the contact point of the links. This may be due to wear resulting from the movement between links or to local deformation of the metal caused by impact loads due to the chain 'snatching'. Snatching can also cause elongation of the links.

In an area where the seabed is sandy and in particular during bad weather or in strong tidal currents, a heavy sand transport can be expected. This will cause severe abrasion of the mooring components.

The thrash section of the mooring has the most pronounced wear as it is continuously moving. Even in waters with a small tidal range, where only a small part of the mooring chain moves over the sea bed, very significant wear may be found. It is common practice to use a larger size chain for the thrash area to account for this extra wear.

3.6. SERVICE LIFE

The service life of chain normally varies from 1 to 5 years, but in sheltered, muddy conditions it may be as long as 20 years. Chain that has exceeded its service life is usually scrapped, downgraded for use in other locations, or a worn part of the chain can be moved to another part of the mooring that is experiencing less wear. The decision to remove chain from service often occurs when the diameter in any point of a link is reduced to a predetermined percentage of its original size: 60% is used by some authorities for buoys in inland waterways, whereas 85% may be used in exposed situations.

On-site inspections to determine the condition of the chain are normally carried out at intervals that may range from 6 to 24 months. This will depend on the safety factors built into the mooring and the environmental conditions at the AtoN location. Experience may show that on a given station, either a lesser or more frequent check is necessary. A detailed inspection regime including elements of predictive maintenance may allow greater or lesser wear down allowances. This regime must take account of wear rate and predicted remaining cross section. Thus, accurate record keeping is a vital part of this inspection process.

Detailed dimensional and material specifications must be maintained to ensure reliable, predictable wear performance of all mooring components. These specifications are of particular importance regarding the planning of future maintenance. It will only be possible to utilise experience gained with the working life and necessary maintenance to a group of moorings to plan the future repair and replacement of similar moorings if the same quality of chains, shackles and other components can be purchased in the future. There are benefits in terms of stockholding and cost reduction to be gained by standardisation of the various components of mooring systems. The quality of the components should be related to the required service life.

It is important to note that the normally quoted regulations for the manufacturers of chain for merchant ships, as laid down by classification societies, only specify the breaking and impact strength of the chain and give no guide to wear and corrosion resistance. A ship normally spends little time at anchor, and so the chain does not suffer significant wear and corrosion. Often the chain will last the life of the ship or only be replaced if it has been overstrained.

See IALA Guideline No. 1040 on the Maintenance of buoys and small Aids to Navigation structures.

4. ROPE MOORINGS

4.1. ROPE BUOY MOORINGS

The primary advantage of rope moorings is their light weight and elasticity when compared with chain moorings. Modern ropes can easily match the strength of steel chain and experience has shown that a similar or better working life than chain can be achieved if chafe is carefully avoided.

The conventional chain mooring utilises energy absorption of the chain catenary to absorb much of the wind and wave energy acting on the buoy and prevent this being transferred to the sinker or anchor. The elasticity of the rope performs a similar function and choosing a suitable combination of fibre type and rope construction can optimize this energy absorption.

Chafe and cutting are the greatest dangers to a rope mooring. It is easily demonstrated that a sharp knife will rapidly cut through a piece of rope and any sharp edges presented by rocks, sea shells or the servicing ship's own capstan can rapidly cause permanent damage to the surface of the rope. Allowing the rope to slip on the drum of a capstan or pulling it through an unsuitable fairlead may not only result in abrasive damage but also in localised heating such that the surface fibres of the rope may melt, resulting in significant weakening. Rope may suffer abrasive damage from sand particles in suspension in the water resulting in reduction in breaking load. In areas

of severe marine growth ropes may attract considerable weed and shell fouling. This can make the resistance of the rope mooring unacceptably high in fast flowing streams.

4.2. MOORING DESIGN

The mooring must be designed so that the rope is never in contact with the buoy body or tail tube and is never in contact with the sea bed (although this may not be a problem in areas with soft, muddy bottoms).

These criteria can be achieved in a normal buoy mooring by utilising a ground chain that absorbs the wear on the sea bed to which a rope 'riser' is attached. Floats may be incorporated to keep the rope off the seabed. Floats may also be used in this way in environmentally sensitive areas. The rope 'riser' component of the mooring is of such a length that even at the lowest tides the rope is never chaffing on the sea bed.

The rope may be attached directly to the buoy if the mooring eye is in a suitable position such that the rope will always be clear of the buoy.

In other cases, a short length of chain (or bridle in the case of two mooring eyes) may be used to absorb any chafe.

Cutting by trawl wires may also be a hazard in some areas where commercial fishing takes place. It may be possible to utilise chain in the part of the mooring that may be subject to abrasion from trawl wires.

4.3. ROPE SIZE

The decision on the size of rope to be used will depend on the load imparted by the buoy due to wind/wave action and water velocity, and the strength necessary to lift the sinker (or anchor).

A rope with strength equal to twice the lifting capacity of the servicing vessel may be a safe guide for the selection of a rope to account for the case when the sinker is buried.

Detailed information will be required from the rope manufacturer regarding the energy absorbing properties and practical working load for the chosen rope.

The method to be used to handle the rope may also influence the size of rope chosen.

The user must be aware of the inherent danger resulting from the high levels of energy stored within an elastic rope when under load, which can be released violently if the rope breaks. Proper safety precautions must therefore be observed by personnel while working with rope that is under load.

4.4. ROPE CONSTRUCTION

A great variety of ropes are now available with many different fibre types as well as types of construction. The use of natural fibre ropes for load carrying applications has almost disappeared. Natural fibre ropes have low strength, will have a short life when compared with synthetic fibres and are no longer cheaper than their synthetic counterparts.

Traditional 3-strand rope construction has also largely been superseded by plaited or braided constructions where high strength and long life are the primary requirements.

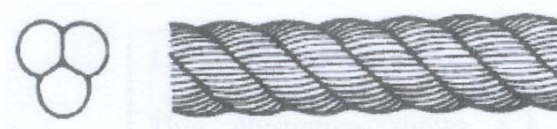


Figure 16 3-strand Construction

This is the oldest and simplest rope construction, consisting of 3 twisted strands laid together. Three strand ropes are hard wearing and easily spliced.

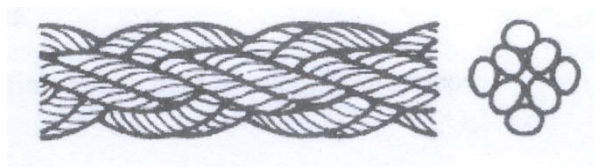


Figure 17 Multiplait Construction

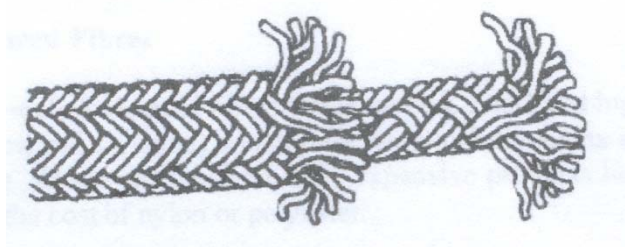


Figure 18 Braided Construction

This illustration shows a rope with a braided core encased in a braided jacket, 3 strand cores are also used. Variations in jacket and core construction allow ropes to be designed for specific working situations. The highest strengths are possible in this construction but splicing is complex.

Each internal strand of the rope may be constructed in several different ways. Manufacturers' information should be studied in detail.

4.5. TYPES OF FIBRE

Modern rope constructions utilise the following fibre groups.

4.5.1. NYLON

This provides high strength, elastic rope with good shock absorbing qualities. However, some ultimate strength is lost due to water absorption if the rope is permanently immersed in water.

4.5.2. POLYESTER

This is widely used to construct high strength, low stretch ropes with good wear resistance and long life.

4.5.3. POLYPROPYLENE

This has been used for cheap, general purpose rope which floats. However recent developments in fibre manufacture and rope construction have resulted in moderate performance ropes, which are considerably less expensive than nylon or polyester.

4.5.4. ADVANCED FIBRES

These include Aramid fibres (trade name Kevlar) and high modulus polyethylene (HMPE, with trade names Spectra, Dyneema and Vectran) which have very high strengths associated with very low stretch. HMPE ropes are also buoyant. However, these are very expensive products, being approximately three times the cost of nylon or polyester.

Rope identification can be difficult as different manufacturers may use trade names for fibre type rather than generic names.

Some HMPE rope constructions are very easy to splice.

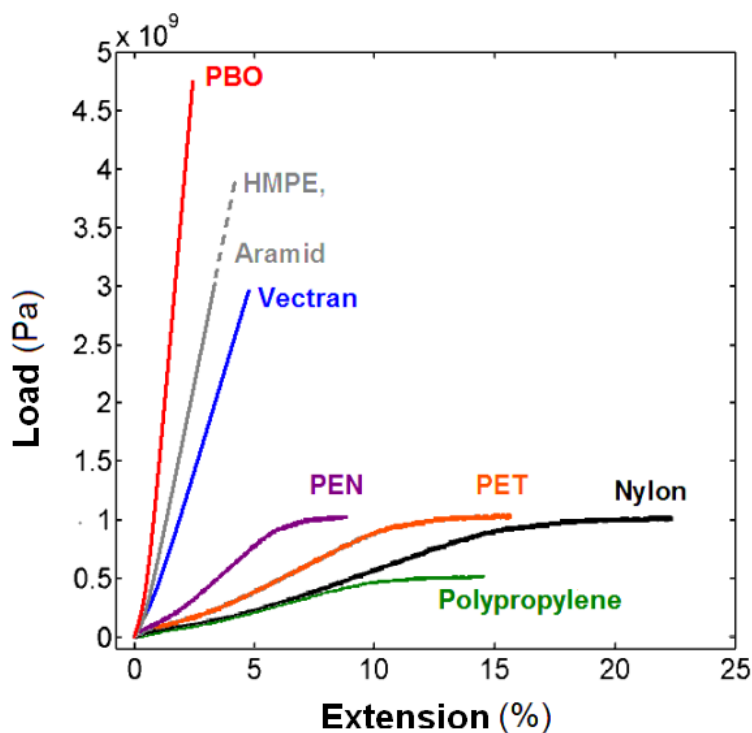


Figure 19 Behaviour of different types of fibre under traction

4.5.5. MIXED CONSTRUCTION

Large ropes, such as those used for ship mooring, may be constructed from a mix of fibres to achieve particular performance parameters.

ANNEX D illustrates details of a standard mooring system developed by the Canadian Coast Guard to moor small (less than half meter diameter) buoys in depths up to 30 m.

4.6. ROPE TERMINATIONS

4.6.1. THIMBLES

The use of fibre rope rather than wire rope for towing and mooring ships and oil rigs has led to the development of thimbles which allow ropes carrying very high loads to be shackled to chain or mooring eyes without damaging the rope fibres.

These thimbles completely enclose the rope leaving no unprotected rope surface to chafe against the joining shackle. They may be fabricated from steel tube, cast iron, or high strength plastic. Movement of the rope within the thimble can be further prevented by filling the thimble with a flexible resin system (usually polyurethane); however, opinions differ as to the need for this process.

4.6.2. SPLICES

The modern rope constructions (i.e. braided and plaited) allow high strength splices to be made when the rope has been installed around the thimble. It should be noted that detailed splicing information must be obtained from the rope manufacturer and that these instructions have to be followed precisely in order to retain the majority of the rope strength at the splice. Special tools will be needed for splicing braided rope and training of those making the splices in any modern rope construction will be necessary.

The mooring calculation must take into account the reduction in strength resulting from the splices, usually on the order of 10% for correctly made splices.

4.6.3. HYBRID ROPE/CHAIN MOORINGS ('COMPOSITE MOORING')

One of the most successful applications of rope has been for the 'riser' (see 'Riding Chain' Figure 1) component of deep-water buoy moorings. The lighter weight of the rope component will allow a standard buoy to be used at stations where the weight of an all-chain mooring would sink the buoy. Alternatively, the lighter weight of the rope mooring might allow a smaller buoy to be used when compared with the size of buoy that would be required to support the chain mooring (providing daymark size and focal plane height are adequate).

The design of the buoy being used must be carefully examined to ensure that the riding performance of the buoy is adequate if the rope mooring is used. Some buoy designs rely on chain weight to achieve positive stability.

This type of mooring does not work well for shallow water applications.

4.6.4. TENSION LEG MOORINGS

Rope moorings are particularly suitable for tensioned mooring configurations such as spar buoys and resilient beacons, where the mooring goes directly from the buoy to the sinker and tension in the mooring line holds the buoy upright. The rope being in tension is not in danger of chafing on the seabed or on the buoy. This configuration has the advantage of maintaining the buoy precisely on station (i.e. there is no 'swinging circle' as there is with a conventional mooring), but is only practical in areas with little tidal range or current. However, the mooring sinker or anchor will need to be considerably larger than that associated with a conventional chain mooring.

4.7. HANDLING ROPE MOORINGS

4.7.1. DEPLOYMENT

When compared with chain, rope is light and easy to manually handle. Because of their light weight, the components for quite large moorings can be moved about onshore or on deck by hand. Moorings can be deployed by flaking (faking) the rope on deck (or in a flaking box, a large version of a line throwing gun rope box). The buoy is placed in the water, the sinker and ground chain simply pushed overboard (or released by cutting lashings), and the rope will follow into the water.

The deck must be clean and free from sand, and the deck edge must be sufficiently smooth so as not to damage the rope.

4.7.2. RECOVERY

If the mooring is to be lifted for removal or inspection, then two areas need special attention:

- 1 Any fairlead that the rope runs over must be of sufficient diameter for the rope used, be of the roller type, and present no sharp edges.
- 2 The winch or capstan must be designed for handling rope, and must not allow the rope to slip on the winch drum when under load.

Conventional capstans, as used for tensioning mooring rope, may be capable of recovering a rope mooring. However, their tendency to allow the rope to slip on the capstan drum will result in considerable heat being generated at the rope/drum interface, which will result in serious damage to the rope. Successful techniques have been developed using large spooling winches where the rope is wound onto a large rotating drum. This technique is limited by the length of rope, and hence the number of moorings that can be carried on the drum at any one time.

The preferred method, where a large number of rope moorings are to be handled, is to use a specialised rope hauling winch. These can be installed at the vessel's deck edge so that the rope can lead directly to the winch without a fairlead being required. The winch consists of an arrangement of large rubber wheels, which grip the rope without causing damage to the surface fibres. The rope usually only passes over a segment of hauling wheel rather than being wrapped around a drum and can thus be placed in, or removed from, the hauling winch as may

be necessary. This type of winch placed on the deck edge also has the advantage that there is no rope under load passing across the vessel's deck, which may present a serious hazard, should the rope break.

An alternative concept is to incorporate handling loops or shackles in the rope allowing the mooring to be hoisted in sections by the deck crane.

The deep water mooring design used by the French authority ensures that the ground chain is sufficiently long so that as the rope part of the mooring is retrieved, the tension in the rope will only be the weight of the ground chain being lifted. The weight of the sinker will not be felt until all the rope has been recovered and the vessel is lifting the chain part of the mooring.

4.8. SAFETY

It must be noted that the energy stored in the more elastic types of rope when under tension may be considerable, and will be released violently if the rope breaks. Suitable precautions must be taken to ensure that no personnel will be in any area that may be swept by the end of a broken rope.

5. ELASTIC MOORINGS

5.1. INTRODUCTION

As the 'on station' life of navigation buoys has increased, the wear of the mooring chain has become the controlling factor in planning service intervals. The continuous movement of the chain links and abrasive particles suspended in the water will cause the chain to wear. This wear can be reduced if the mooring line can be kept under constant tension. A solution to this problem is the fully elastic mooring line. This can be designed to always be under tension to minimise wear.

The elastic mooring can be compared to the rope mooring discussed earlier in this Guideline, the difference being that the upper part of the mooring line consists of a length of rubber cord which will absorb the energy caused by the motion of the buoy and compensate for the differences in water levels, tide, waves, etc.

5.2. ELASTIC MOORING CONSTRUCTION

The elastic cord is made of solid natural rubber. This is capable of considerable elongation and has high tear strength. The rubber cord is installed in parallel with a rope safety line, and is connected to the rope by a simple knot. The different rope lengths are connected by special H-shackles.

5.3. ELASTIC MOORING DESIGN

The dimensions of an elastic mooring are determined by the local sea conditions, the water depth, and the size/shape of the buoy. For chain moorings, a certain length, chain size, and quality of steel are needed to keep the buoy on station for a certain time. For an elastic mooring, the variables to consider are the correct length of rubber cord and the diameter and hardness of rubber needed to provide the necessary elongation to compensate for different water levels and to absorb the buoy's energy.

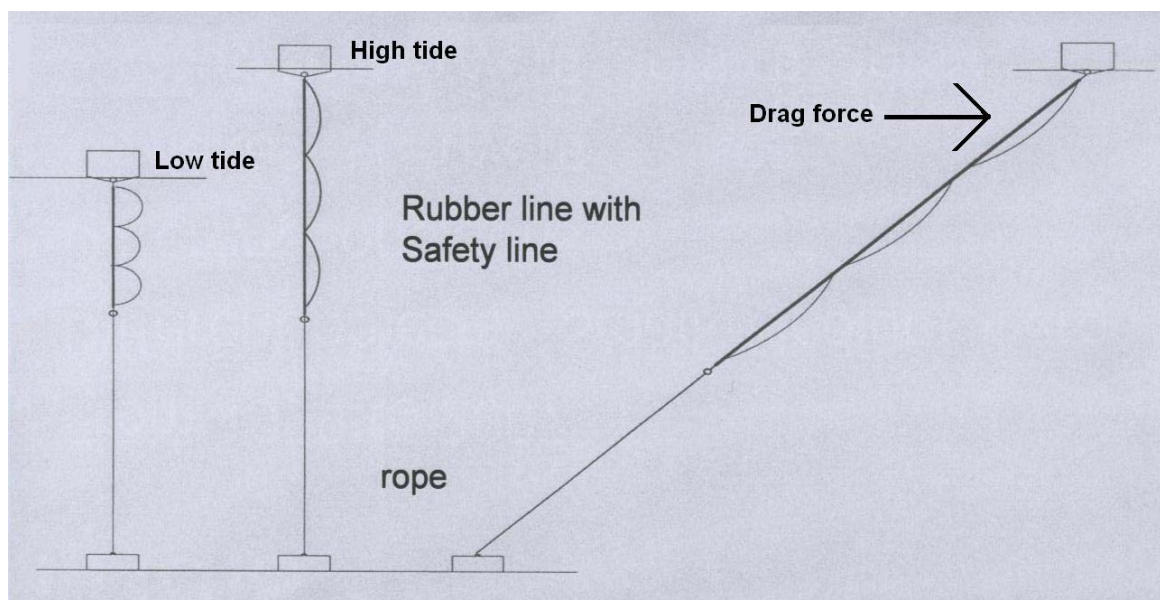


Figure 20 Elastic Mooring Layout

5.4. HANDLING

An elastic mooring can be deployed in a similar way to a rope mooring. For recovery, the rope sections are lifted, length by length, by the crane. A special stopper is required on the deck edge to safely hold the rope during the recovery process.

5.5. ADVANTAGES

An elastic mooring is light in weight, easy to assemble and flame cutting is not required to cut the mooring to length.

An elastic mooring is always under tension and so does not damage the seabed.

The dimension (diameter) of an elastic mooring is much smaller than a comparable chain mooring, so the marine growth is much less. Thus, the elastic mooring has less resistance in water than chain.

A particular advantage is that the elastic mooring can be used in shallow water and breaking waves because the rubber itself absorbs the energy in the system. A chain mooring needs a certain length and weight of chain, and a certain minimum water depth, to function properly. Hence, a chain mooring is not a good solution in shallow water and breaking waves.

An elastic mooring is very light in weight, and so has almost no influence on the reserve buoyancy of the buoy.

As the mooring line is always under tension, the buoy has a very high positional accuracy.

The very smooth absorption of energy by the rubber cord results in the forces in the mooring line being approximately half of those in a chain mooring.

As the mooring line is always under tension, there is little wear and therefore almost no maintenance. For this reason, the lifetime of an elastic mooring is approximately double that of chain.

6. EXAMPLES OF SPECIALISED RIVER MOORINGS

The following examples illustrate special moorings that have been developed for use in fast flowing rivers with a current flow in one direction only.

6.1. GERMANY

6.1.1. RIVER BED FIXED MOORINGS OF BUOYS ON THE RIVER RHINE

In the area of St. Goar, the waterway is 120 m wide and winding. The current is about 7 kn and the ground is mainly rock. This section of the river is used by ships and pushing units up to a length of 140 m and a width of 15 m. About 70.000 ships carry 67 million tons per year. For safety reasons, only one-way traffic is allowed, and a VTS-Centre is installed to control traffic. In this area about 1/3 of the buoys are moored to mooring rings set in the rock bed of the river. Sinkers would be too large and could be a danger for the passing ships.

- Data of the waterway:
- Current of 3.6m/s (7 kn);
- Minimum width 120 m;
- Minimum depth (not more than 20 days per year) 1.9 m;
- Average depth 3.4 m;
- Seasonal variation of depth 1.39 m to 9.29 m.

Mooring system data:

- Depth of mooring fixing 60 cm;
- Mooring ring bar diameter 50mm;
- Ground chain length 12 m, bar diameter 18-20 mm;
- Riding chain length 15 m, bar diameter 10 mm;
- If the mooring ring is lost then temporary chain length (used until a new mooring eye is installed) 40 m, bar diameter 20-22 mm (with a weight of 600-700 Kg).

Buoy data:

- Lightweight Steel buoy with 1 m diameter;
- Volume 400 litre;
- Filled with polystyrene, in case of leakage 40 litre of water could ingress;
- Weight 62 Kg + tail tube 13 Kg + counterbalance 8 Kg = 73 Kg.

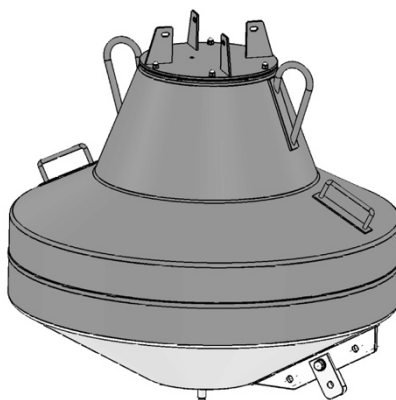


Figure 21 Type of River Buoy

6.2. THE NETHERLANDS

6.2.1. MOORING WITH ANCHORS ON THE RHINE

A 125kg anchor is used rather than a sinker.

The chain length is 25 m including the bridle of 4 m.

The diameter of the chain is 22 mm.

The water depth varies from 3 m to 12 m.

The current is usually around 4 kn, but may increase to 6 kn.

The second line on the buoy is called the 'neuringline'. The bottom part is chain of 10 mm and the upper part is rope. This 'neuringline' is used by a small vessel to tow the buoy and anchor in to a new position, required by changes in water levels. The small vessel can easily lift the anchor in this way and move the buoy and mooring to a new position. Buoy lifting is not necessary and the small vessel would not be able to lift a sinker that would have the same holding power as the anchor.

The buoy used is made of steel, has a diameter of 2.00 m, a weight of 2500 kg and the draught is 1.90 m.

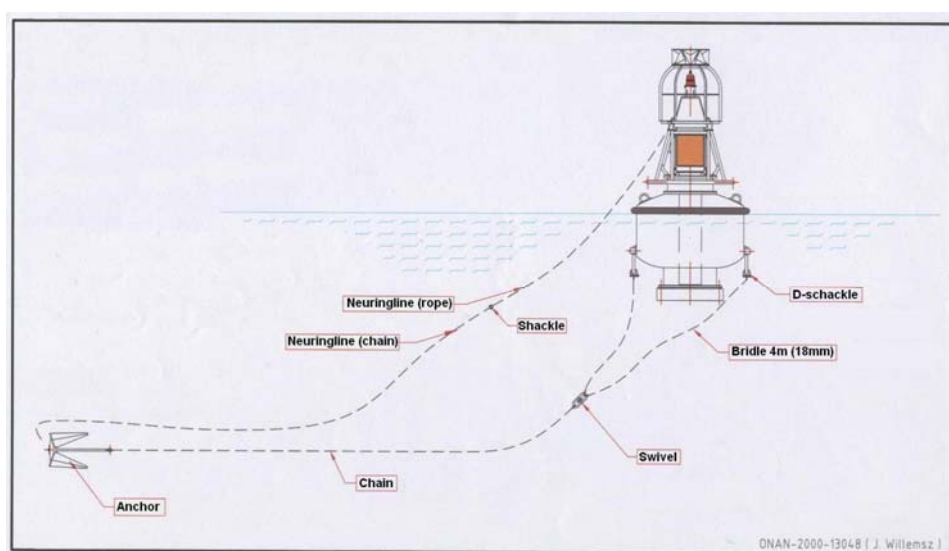


Figure 22 River Mooring

7. ACRONYMS

AtoN	Aid(s) to Navigation
BNG	New Generation Buoy
Cd	Drag coefficient
cm	centimetre
DIN	German steel grading
HMPE	High modulus polyethylene
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
kg	kilogram
kgf	kilogram-force
kg/m	kilograms per metre
kg/m ³	kilograms per cubic metre



kn	knot(s) (nautical mile(s) per hour)
LANBY	Large navigation buoy
m	metre(s)
m ²	square metre(s)
m ³	cubic metre(s)
mm	millimetre
m/s	metres per second
m/s ²	metres per second squared
N	Newton(s)
N/mm ²	Newtons per square millimetre

ANNEX A DRAG COEFFICIENT

A 1. DETERMINING THE RESISTANCE OR DRAG COEFFICIENT

There is little or no published work on the resistance coefficient of buoys, although this value is very important when calculating the loads in the buoy mooring. The Netherlands' Authority carried out practical towing tests on 9 April 2002 in the Haringvliet, near the dam, to determine the coefficient in question. The buoy tender, the 'Vliestroom' carried out a number of towing trials with a standard 6.5 m³ skirt type, buoy body, towing from South to North at various speeds.

A 2. DATA ON STEEL 6.5 M³ SKIRTED BUOY

Diameter of buoy body:	2.55 m
Diameter of skirt:	1.78 m
Draught:	1.35 m
Surface area of the buoy:	2.97 m ² , at a draught of 1.35 m

A 3. TOWING TEST

The buoy was towed in two ways, first with a rope tow line and then with a rubber cord with a diameter of 35 mm.

To prevent the propeller wash from affecting the measurements, the buoy was towed from the end of the crane arm while the crane arm was athwartships. The tensile force logger was located in the single section of the towing line.

A 3.1. COMPOSITION OF TOWING LINE

1st test: mooring eyelet, branch of rope (l = around 5 m) tensile force logger, length of rope around 10 m, hoisting rope. Horizontal boom.

2nd test: mooring eyelet, branch of rope (l = around 5 m) tensile force logger, length of rope around 10 m, lifting boom. Horizontal boom.

The buoy was then towed by the Vliestroom at a speed of 1, 2, 3 and 4 kn with the rope line and at a speed of 1, 2 and 3 kn with the rubber line.

During the towing, the buoy did not yaw, rotate or oscillate.

The buoy moved at a constant speed through the water. It made no difference to the behaviour of the buoy whether the rope or rubber tow line was used.

As the speed increased, a wave pattern developed along the buoy, with a rising bow wave and a wave trough at the point where the breadth of the wave was the greatest.

During the test with the rubber line, the line became longer as the dragging speed increased. At a speed of 3 kn, the buoy was approximately in line with the rear of the superstructure, while in the beginning, it was approximately in line with the rear of the working port.

A 4. RESULTS

The forces measured varied from 20 Kgf to around 400 Kgf as the towing speed increased from 1 to 4 kn.

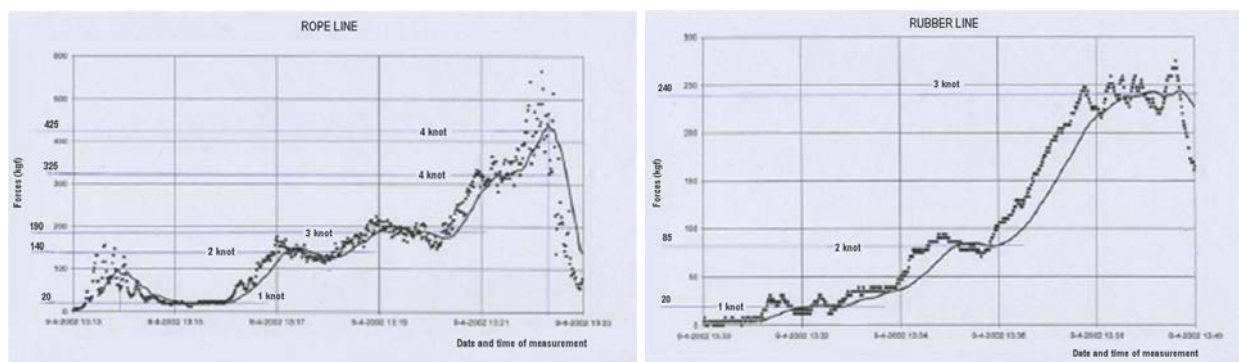


Figure 23 *Forces when towing with rope line and Forces when towing with rubber line*

Based on the forces measured, the resistance of the 6.5 m³ buoy was calculated according to the towing speed. The measured values, which deviate slightly from the pattern, may be explained by the fact that it was found to be very difficult to tow the buoy at a precise, constant, low speed.

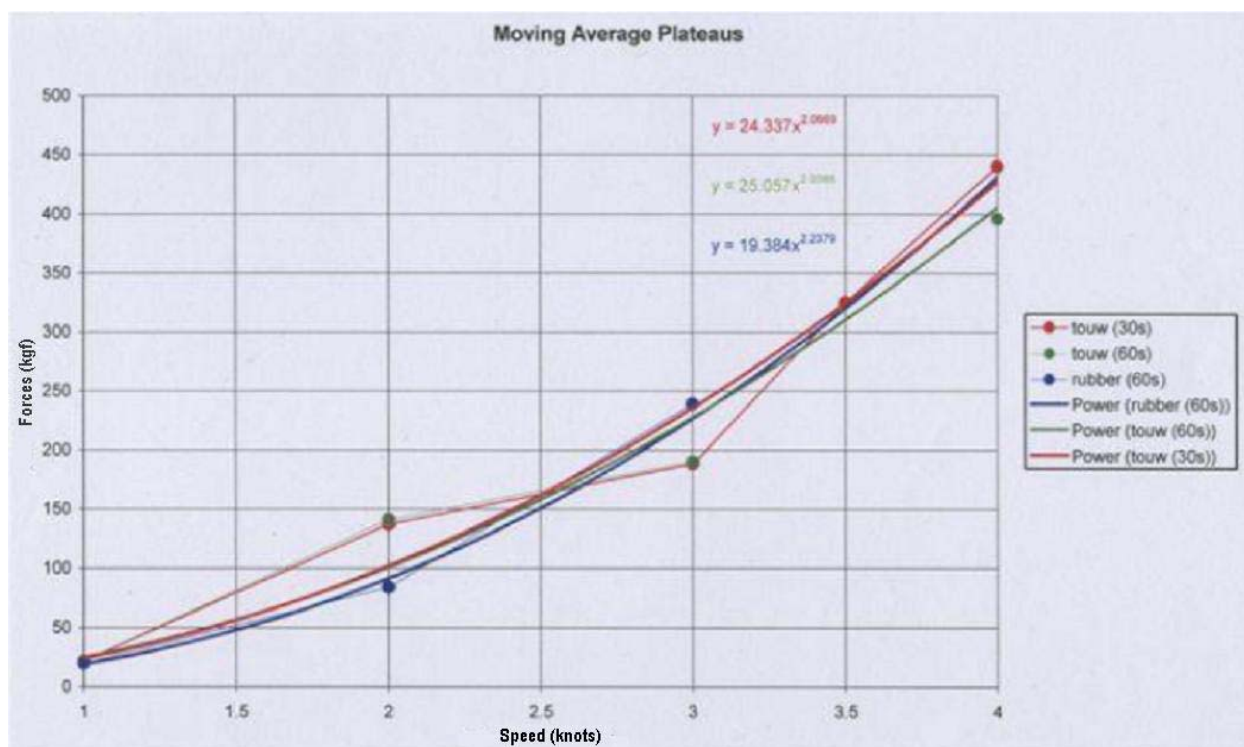


Figure 24 *Graph showing the resistance of the buoy when towed at various speeds*

A 5. DETERMINING DRAG COEFFICIENT (CD)

Using the forces measured, one can calculate the Cd for this type of skirted buoy.

Table 2 *Table showing towing forces with rope*

V (knot)	Force (Kgf)	Cd	Remarks
1	20	0.53	
2	140	0.93	Random peak
3	190	0.55	
4	325/ 425	0.54/ 0.70	

Table 3 *Table showing towing forces with rubber line*

V (knot)	Force (Kgf)	Cd
1	20	0.53
2	85	0.56
3	240	0.70

A 6. CONCLUSIONS

The above tables show that the value varies between 0.53 and 0.56 with peaks of up to 0.93. Assuming that measuring errors and deviations in the towing speed caused the peaks it can be assumed that, for this type of buoy, a Cd value of 0.55 can be applied.

ANNEX B COMPARISON OF MOORING LOADS ON A RUBBER OR CHAIN MOORED NAVIGATION BUOY

B 1. INTRODUCTION

A numerical study, based on a simple model of a chain moored navigation buoy gives insight in the load on the chain. The same model is used to evaluate the mooring forces on a rubber moored navigation buoy. Comparison of the results explains why in shallow water rubber cords perform better than chain moorings.

Initially mooring a navigation buoy with rubber was faced with scepticism. Experience has shown that chain moorings sometimes break. Replacing it by a stronger (or longer) chain makes the mooring survive. Based on this experience it is contra-intuitive that a rubber cord, having only a fraction of the maximum load, can handle the mooring forces equally well or sometimes even better. Now, after some 5 years of experience (by the Netherlands Authority) using rubber cords to moor navigation buoys, this initial scepticism has changed to confidence and willingness to accept a rubber cord as a suitable mooring material. This paper deals with some background considerations concerning the mooring forces in both the chain and the rubber cord moored navigation buoy, and shows that a proper rubber cord mooring limits the mooring load well below the maximum force a rubber cord can handle.

B 2. THE INITIAL CONFLICT

Basically the mooring of a buoy serves two conflicting purposes. On the one hand it has to keep the buoy on position, while on the other hand the mooring has to allow the buoy to follow the dynamics of the waves to a certain degree in order to reduce the mooring forces. This conflict most clearly shows up when the buoy is picked up by a wave at the moment the end of the mooring line length is reached. Especially in shallow water, the chain mooring suddenly comes to its end resulting in enormous peak forces. A rubber cord can elongate, to a couple of times its original length, smoothing the stop of the buoy and thus avoiding peak forces. In the next sections of this presentation the results of a numerical simulation of a chain and rubber moored navigation buoy are presented. Finally, in the last section this topic is presented on the basis of the concept of conservation of energy.

B 3. DESCRIPTION OF THE MOORED NAVIGATION BUOY AT SEA

In order to make the results as transparent as possible, the sea, the buoy and the mooring are reduced to their most essential features. The buoy is modelled as a single-point moored buoy which keeps perfectly upright at all times. A train of breaking waves is modelled as a wall of water having a width equal to its height (h). The breaking waves are separated by still water of three times the wave width.

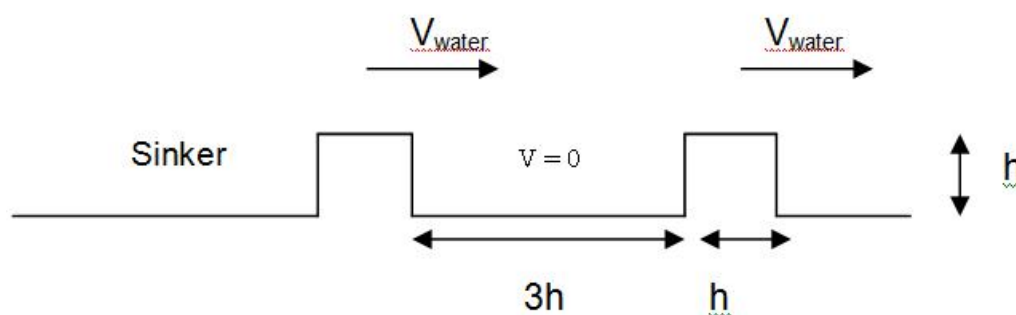


Figure 25 A train of breaking waves

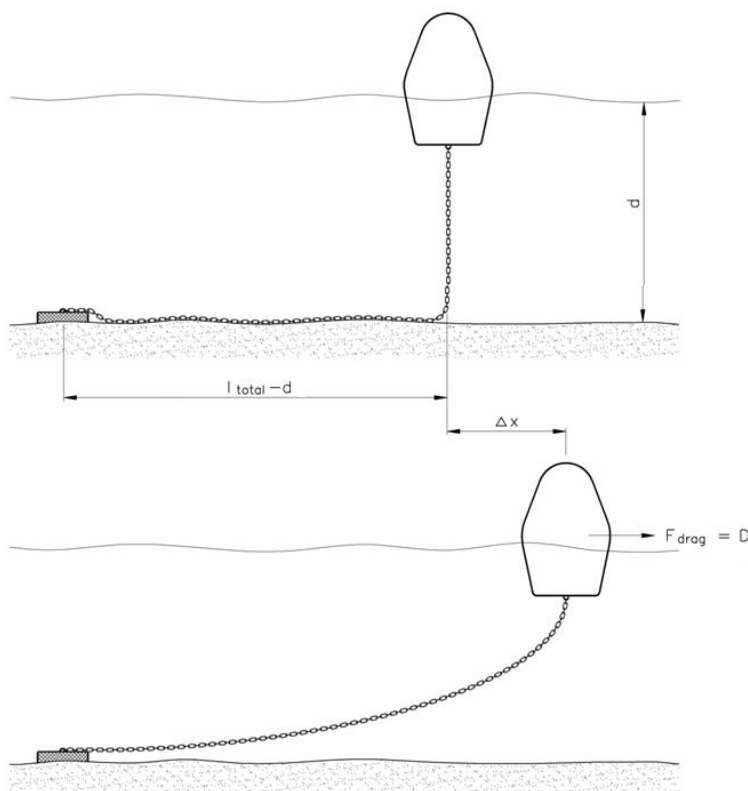


Figure 26 *The horizontal force on a buoy as a function of the displacement ΔX*

Although the chain mooring is at least two dimensional, it is cast into a one-dimensional model. This is done by calculating the horizontal-force/displacement relation of a chain moored buoy. The horizontal force of the chain on the buoy is calculated as a function of the displacement (ΔX) from the zero-velocity position (see Figure 26).

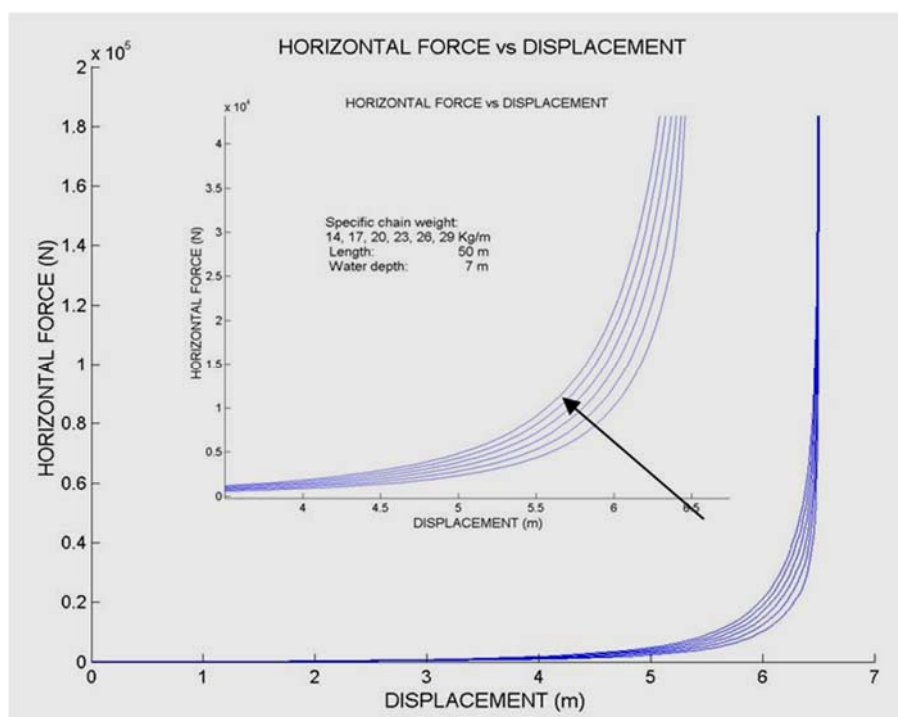


Figure 27 *The horizontal force on a buoy versus the displacement of the buoy from its zero-current position*

In equilibrium, this force equals the drag force on the buoy. In a dynamic situation this force also accelerates (decelerates) the buoy. This chain-force/displacement relation depends on the specific weight (weight per meter), the length of the chain and last but not least the water depth. In Figure 27 the horizontal-force versus displacement is presented for various values of the specific chain weight. As expected, the lighter the chain is, the sharper the edge in the force-displacement relation.

The impact of the varying specific chain weight can be shown by applying the chain in a mooring. The buoy, the sea and the mooring are defined as follows:

The specifications of the buoy are:

Underwater surface area:	1 m ²
Total surface area:	2 m ²
Mass incl. added mass:	300 kg
Mass incl. added mass when flushed over:	400 kg
Drag coefficient:	1

The specifications of the sea are:

Water depth:	7 m
Water velocity of the breaking wave:	8.3 m/s
Water velocity in between the breaking wave:	0 m/s
Height of the breaking wave:	7 m
Distance between two breaking waves:	21 m

The specifications of the chain mooring are:

Length	50 m
Specific weight (in water)	14, 17, 20, 23, 26, 29 kg/m

When the breaking wave hits the buoy, the buoy is completely flushed over. Tilting of the buoy is not taken into account. The inertia of the chain itself is neglected, as is the drag of the chain. The velocity of the water in a (breaking) wave is determined by physics and depends, in shallow water, on the water depth. The standard water depth in this numerical study is 7 m. For reasons of compatibility, the velocity of the water in the breaking wave is considered constant throughout this study independent of the actual water depth.

The mooring force as a function of time when the breaking waves pass the buoy is presented in Figure 29. Figure 28 zooms in on the observed peak forces. For all chains, the mooring force comes to a steady level, equal to the drag force on a steady buoy. The way this steady state force is reached depends very much on the specific weight of the chain. As can be seen in Figure 28, with the heaviest chain the force smoothly increases until the equilibrium force is reached. The light-weight chains on the other hand do not slow down the buoy sufficiently before the end of the chain length is reached, and the mooring force peaks to approximately 10 times the steady state value. Here one can see what the problem is with light-weight chain; light-weight chain is not heavy enough to keep the mooring forces small. In that case the mooring forces can reach very high peak values, with all the undesired possible consequences.

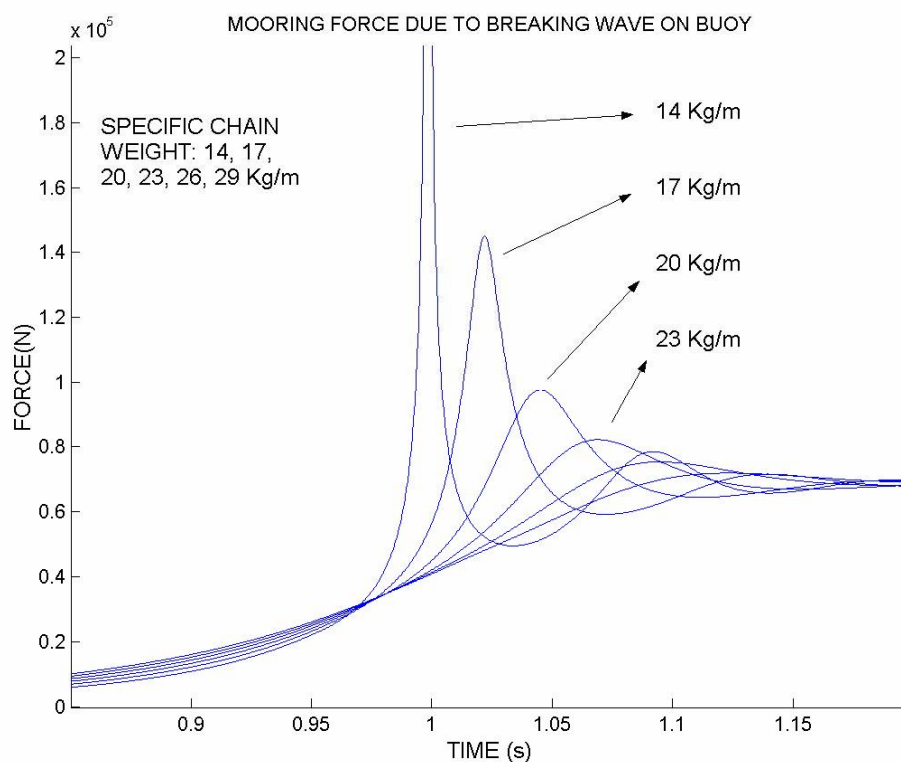


Figure 28 *The horizontal force on a buoy as a breaking wave strikes*

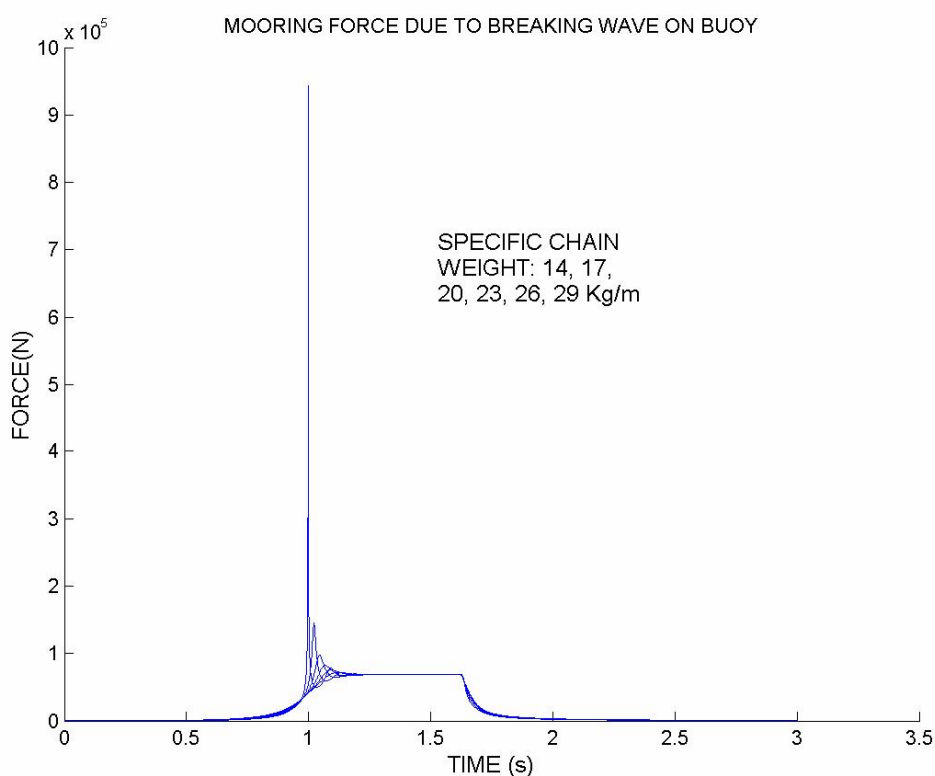


Figure 29 *The horizontal force on a buoy while a breaking wave passes*

B 4. SHALLOW WATER

In the previous section the mooring design was completely in our hand. With a proper choice of the chain, both in specific weight and in length, the mooring forces could be kept low. In the case of shallow water, the key parameter is the precise water depth and this is not controlled by man. From the configurations described in the previous section, the chain with a specific weight of 20 kg/m is chosen, and the water level is taken 3, 4, 5, 6 and 7 m respectively. The mooring forces due to a passing breaking wave are presented in figure 30. At $t = 0$ the front of the breaking wave is at the buoy's equilibrium position in case of zero water velocity. With decreasing water level from 7 to 4 m, the maximum force increases dramatically. At 3 m the peak force increases to over 10 times the static force of the braking wave. The impact of this observation is that in an occasional case of lower water level than expected the mooring design is not adequate anymore and can fail.

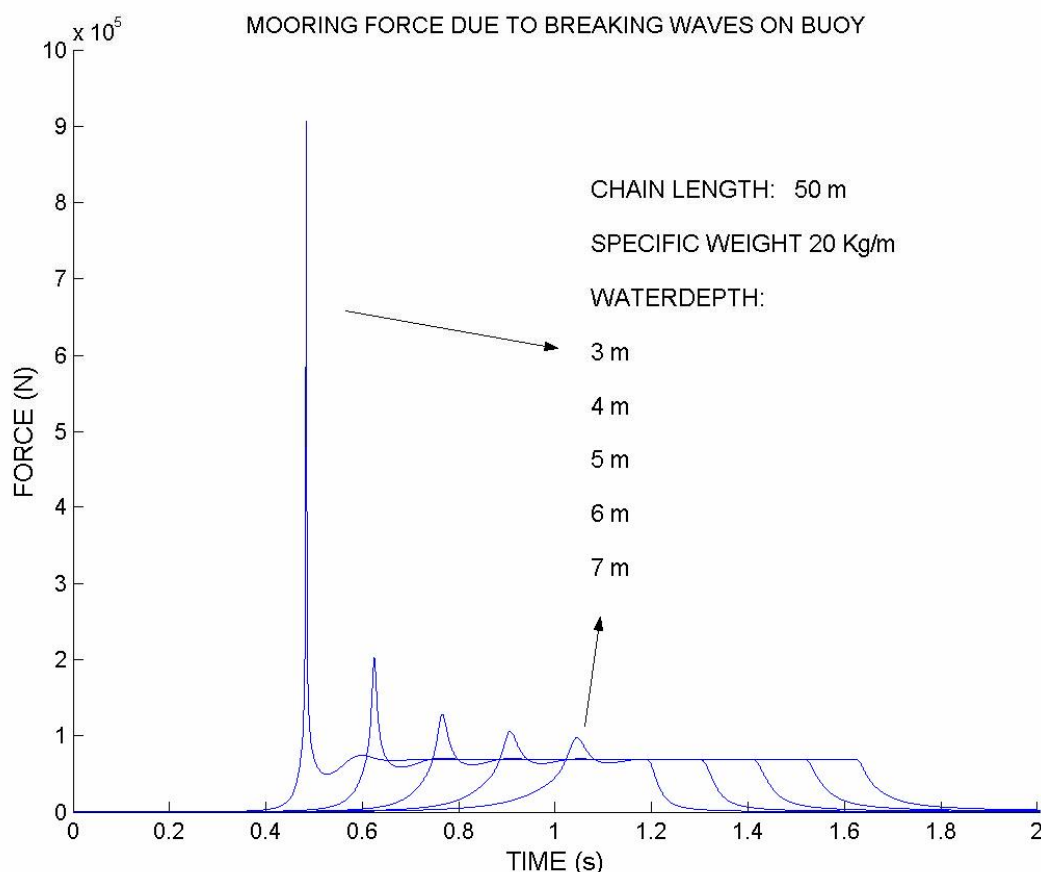


Figure 30 *The horizontal force on a buoy while a breaking wave passes*

B 5. RUBBER MOORED NAVIGATION BUOY

The sharp peaks in the mooring force in shallow water under breaking wave conditions can be avoided by applying a rubber cord in the mooring. When the buoy is picked up by the wave, and the mooring line reaches its end, the buoy has to be slowed down. The rubber cord will do this in a gradual manner, thus avoiding high peaks in the mooring force. In order to demonstrate this, the numerical simulation presented in the previous section has been performed with rubber cord, instead of chain. The used rubber has a diameter of 50 mm, and a hardness of 60 Shore A.

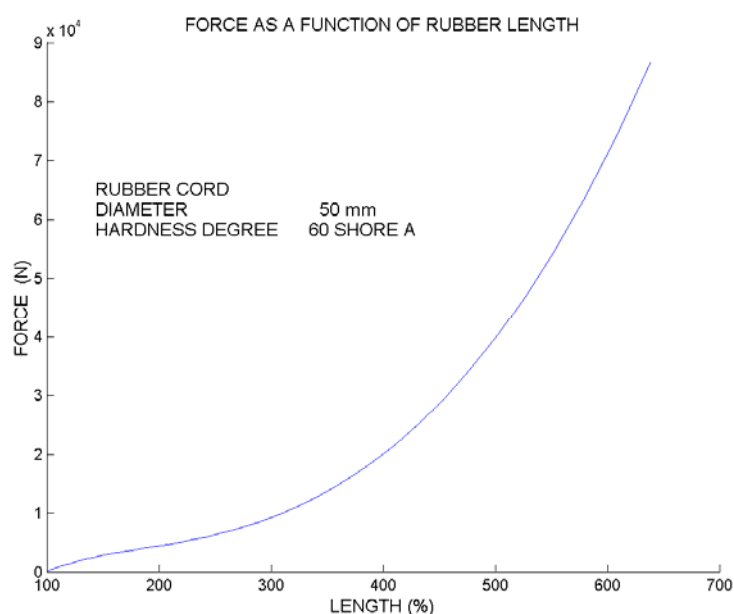


Figure 31 *The force on a rubber cord as a function of the relative length*

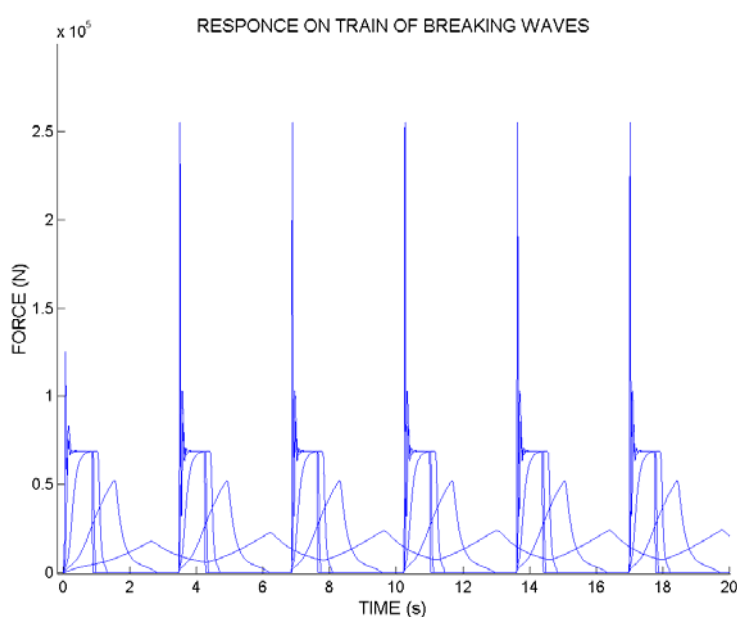


Figure 32 *The mooring force on a buoy moored with a rubber cord while breaking waves pass. Rubber cord length: 2 cm 8 cm 32 cm 1.3 m 5.1 m*

The force elongation relation of the used rubber is presented in Figure 31. Elongation is presented as a percentage, 100 % corresponds to an un-stretched condition, at 200 % the rubber cord is doubled in length. For varying length of the rubber cord the simulation has been performed, see Figure 32. Figure 33 is zoomed in on the second breaking wave pass. The peaked mooring forces are due to the simulation with an unrealistically short rubber cord of only 2 cm! With increasing length of the rubber cord the peak immediately disappears. Further increase of the rubber cord length results in a reduction of the maximum force to a level below the steady state level. In those cases, the buoy can move along with the wave during the whole passage and is pulled back during the time in-between two breaking waves.

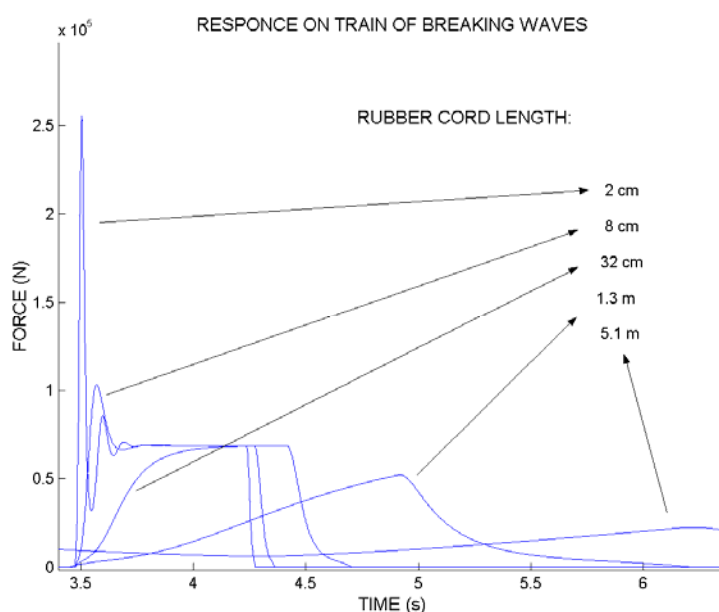


Figure 33 *The mooring force on a buoy moored with a rubber cord while breaking waves pass. Rubber cord length: 2 cm 8 cm 32 cm 1.3 m 5.1 m*

With the first breaking wave passing the buoy, the maximum forces are not as high as during the sequential waves. At $t = 0$ the rubber cord is in the un-stretched condition, and the front of the breaking wave just tips at the buoy. When the breaking wave passes the buoy, it is displaced in the positive direction. After this passage the buoy is pulled back by the mooring. At the time the front of the second wave hits the buoy, it may be on the left or right side of the original position point. With this new starting position, the second pass will be slightly different.

B 6. ENERGY CONSIDERATIONS

The applicability of the chain and rubber mooring can be considered from an energy point of view. When the buoy is picked up by a (breaking) wave it will gain kinetic energy. This energy has to be absorbed by the mooring. A chain mooring absorbs this energy by lifting up chain. The kinetic energy is transferred to potential energy. The rubber mooring transfers the kinetic energy into internal (elastic) energy. Here the difference shows up, the energy a chain mooring can absorb depends on, among others, the water depth. The energy a rubber cord can absorb only depends on the cord itself. Thus, in shallow water, elastic mooring has the greatest asset.

B 7. CONCLUSION

By numerical analysis it is shown that a buoy which is not adequately moored may suffer from high force peaks in the mooring line. The quality of the chain mooring depends on the length and specific weight of the chain and the water depth. If the chain is too light in weight, or not sufficiently long, peak forces can increase dramatically. The quality of the rubber moored buoy only depends on the rubber cord itself. Peak forces can be avoided independently of the water depth, making the rubber cord mooring superior in shallow water situations.

ANNEX C EXAMPLE OF A MOORING DESIGN

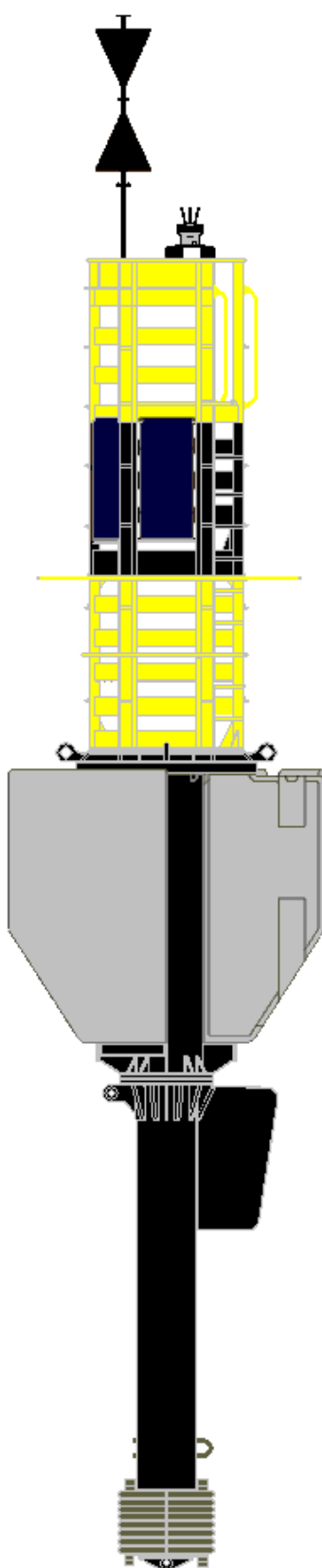


Figure 34 *A8L new generation buoy*

C 1 CHOSEN SITUATION

This numerical application has been carried out for a Bouée Nouvelle generation A8L. The aerodynamic and hydrodynamic drags have been calculated as shown in section 3.3.1.1. 'Transitional Mooring Loads'.

Environmental conditions for the example

Buoy:	New Generation Buoy (BNG) A8L
Depth:	20 m
Tide:	6.9 m
Maximum wave height:	5 m
Maximum wind speed	180 km/h
Maximum current speed:	2 knots
Chain diameter:	35 mm
Chain type:	3D
sinker density:	2100 kg/m ³
Steel density:	7850 kg/m ³
Steel tensile strength:	500 N/mm ²
Air density:	1.29 kg/m ³
Water density:	1024 kg/m ³
Internal Friction angle of the seabed	45°
Type of Buoy	A8L
Superstructure surface	5,06 m ²
Superstructure drag coefficient	1.2
Upper float surface	2.73 m ²
Upper float drag coefficient	1
Lower float surface	2.7 m ²
Lower float drag coefficient	1
Tail surface	2.22 m ²
Tail drag coefficient	1
Buoyancy of complete buoy body	9.5 m ³
Mass with equipment	4.2 T

Linear immersed mass of the chain: 23kg/m³

Tension on the sinker--- see Equation 9 'Taut mooring Loads'

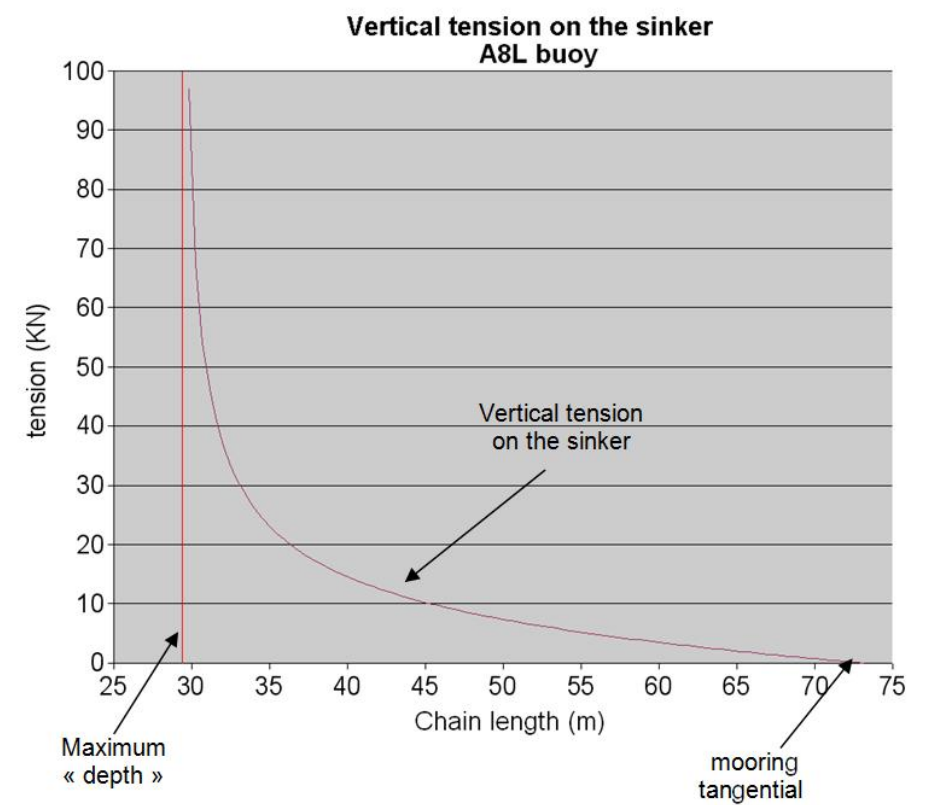


Figure 35 *Vertical tension on the sinker depending on the length of chain*

The vertical tension is equal to zero for slack and transitional moorings.

If the mooring is shorter, the vertical tension on the sinker will be increasing.

If the length of the mooring is equal to the depth, the tension on the sinker will be very high, in reality the buoy will be submerged before this can occur.

With respect to tension on the buoy see section Equation 11 Reserve Buoyancy.

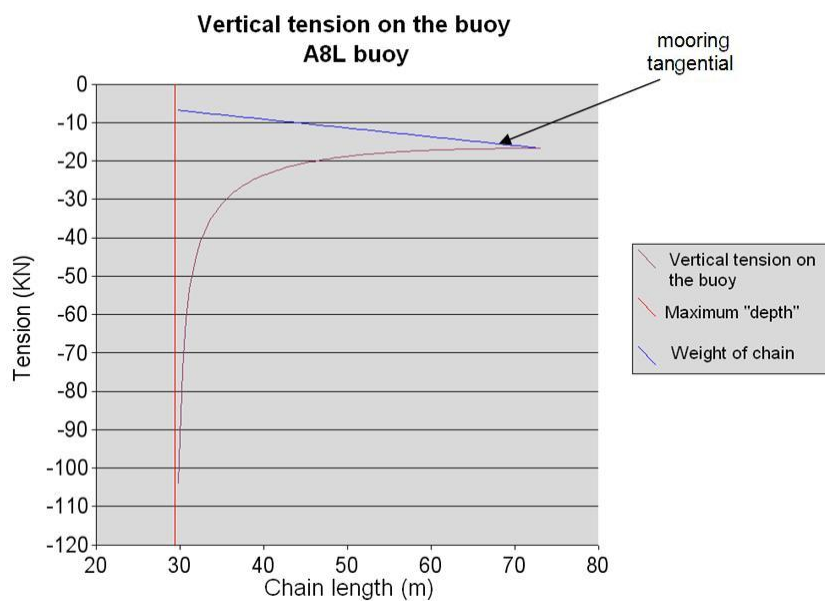


Figure 36 *Vertical loading on the buoy*

In the case of a tangential mooring (slack or transitional) the tension on the buoy is only due to the weight of supported chain, whereas if the length of chain is less than the recommended length for the transitional mooring, the gain in chain weight is not enough to compensate the extra effort due to the tension on the sinker.

With respect to tension on the mooring line see section 3.3.1.3.2 Chain Size

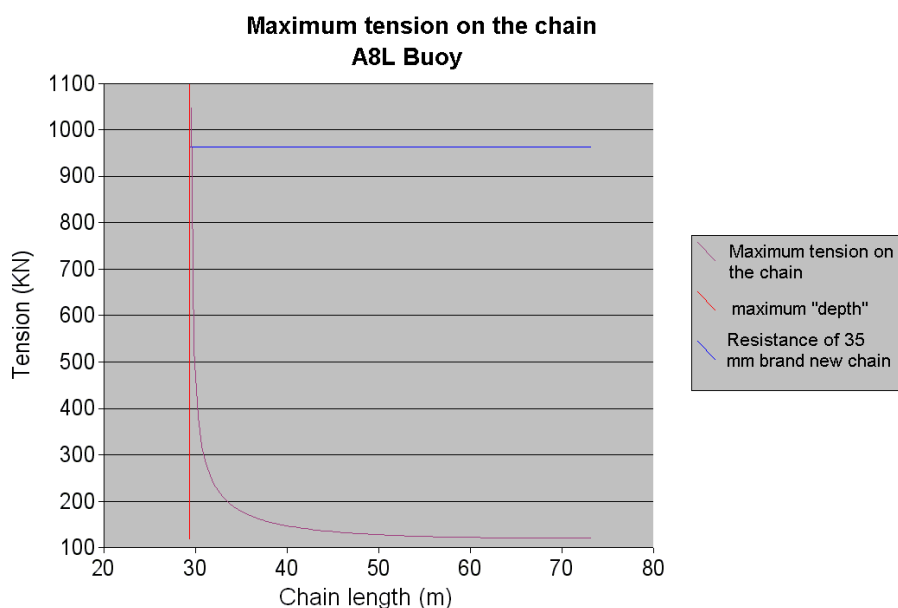


Figure 37 Chain tension

The graph above shows that the 'new' chain strength may not be a problem for the mooring as long as the chain length is not too close to the 'depth'. It follows that if you have a taut mooring, you may not have to choose a higher strength chain. However, the taut mooring can have an impact on chain wear. As the chain is continuously in tension, the rate of wear will be faster with this type of mooring.

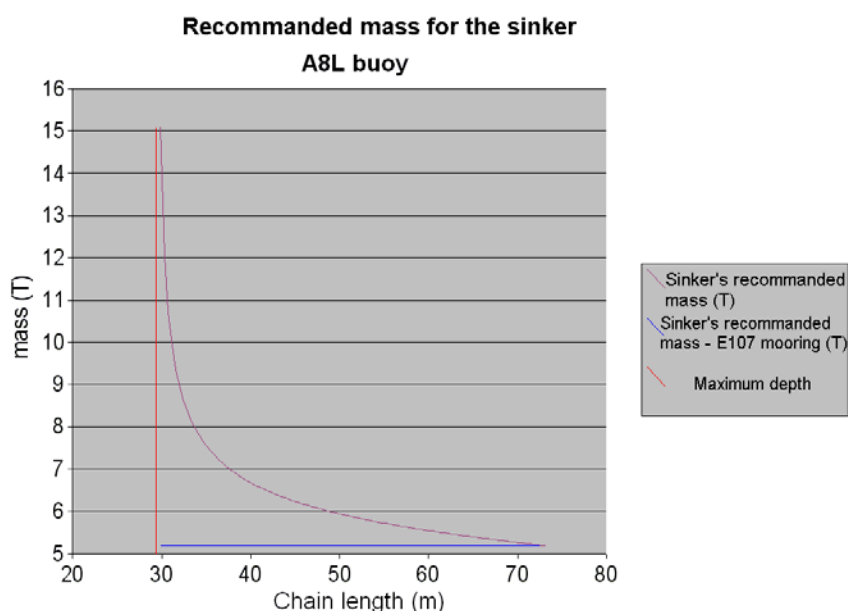


Figure 38 Sinker Mass

Recommended mass on the sinker. See section 3.3.2 'Sinker Weight'

Figure 38 illustrates that taut moorings require heavier sinkers.

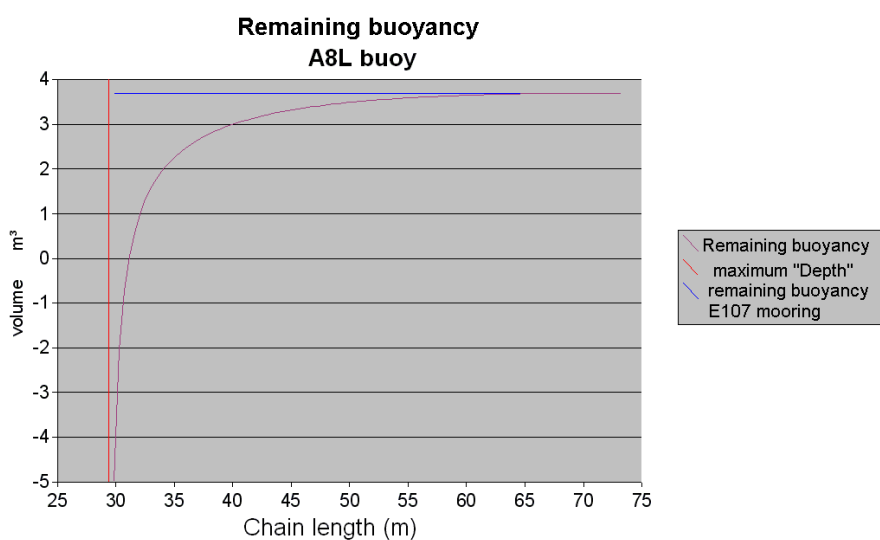


Figure 39 Reserve buoyancy

Similarly, reducing the length of chain causes a reduction of the reserve buoyancy that has to be taken account at the design stage. In some cases, the choice of a larger buoy may be necessary.

ANNEX D SINKERS' DETAILS

D 1 SINKER WITH A SQUARE BASE

These are easier to produce, but not recommended for fast currents sites.

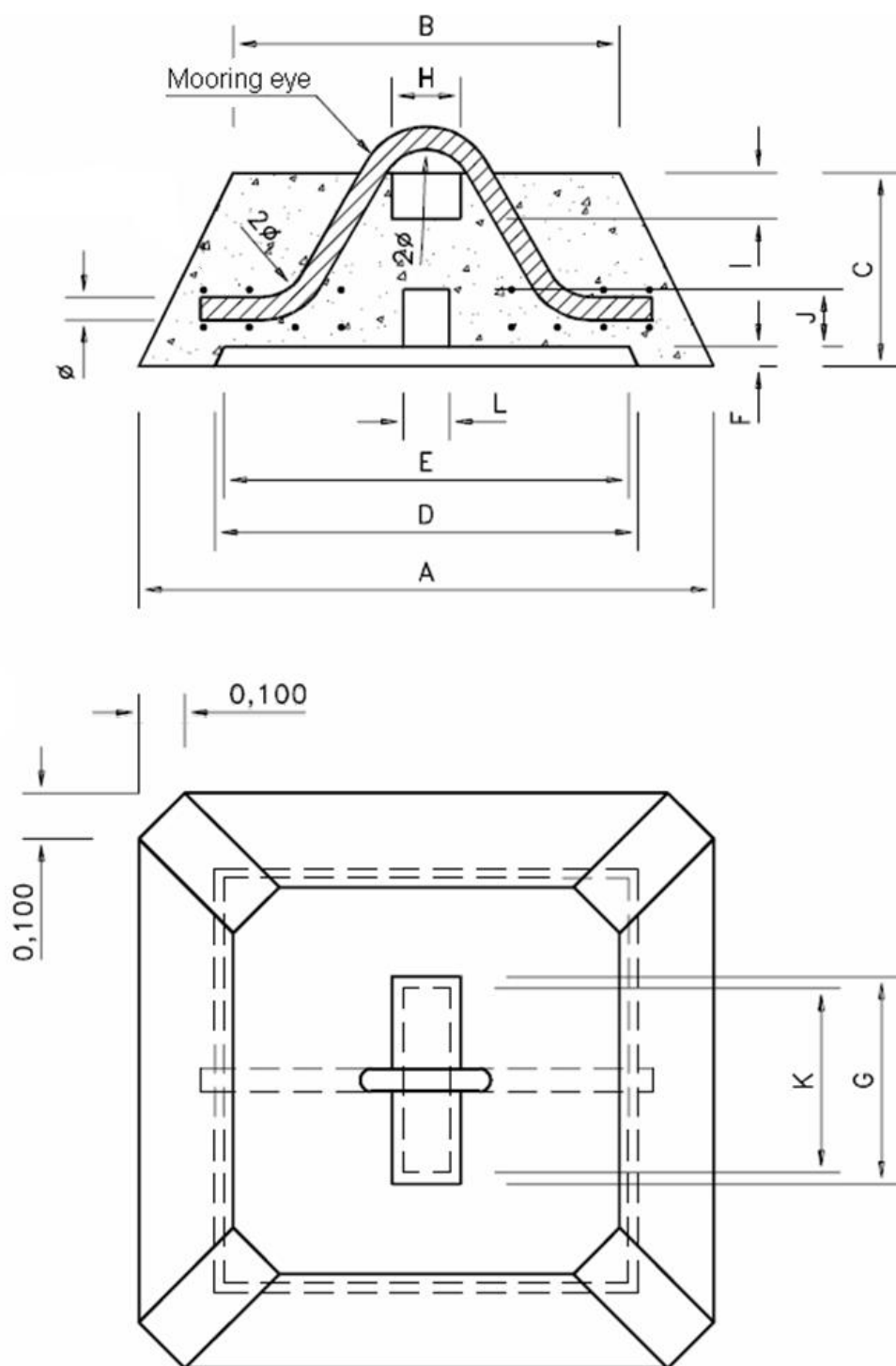


Figure 40 *Square concrete sinker*

Table 4 Concrete sinker dimensions

M	Mass of sinker	500 kg	1000 kg	2000 kg	3000kg	4000kg	6000kg
A	Side of the large base	100 cm	125 cm	155 cm	175 cm	190 cm	215 cm
B	Side of the narrow base (=2A/3)	66.7 cm	73.3 cm	86.7 cm	106.7 cm	133.3 cm	153.3 cm
C	Height of sinker (=A/3)	33.3 cm	41.7 cm	51.7 cm	58.3 cm	63.3 cm	71.7 cm
D	Base of the suction hole (=22A/30)	73.3 cm	91.7 cm	113.7 cm	128.3 cm	139.3 cm	157.7 cm
E	Summit of the suction hole (=21A/30)	70 cm	87.5 cm	108.5 cm	122.5 cm	133 cm	150.5 cm
F	Height of the suction hole (=A/30)	3.3 cm	4.2 cm	5.2 cm	5.8 cm	6.3 cm	7.2 cm
G	Length of re-entrant for shackle (=9 ϕ)	36 cm	45 cm	54 cm	54 cm	54 cm	54 cm
H	Width of re-entrant for shackle (=3 ϕ)	12 cm	15 cm	18 cm	18 cm	18 cm	18 cm
I	Depth of re-entrant for shackle (=2 ϕ)	8 cm	10 cm	12 cm	12 cm	12 cm	12 cm
J	Height of re-entrant for storage (=2.5 ϕ)	10 cm	12.5 cm	15 cm	15 cm	15 cm	15 cm
K	Length of re-entrant for storage (=8 ϕ)	32 cm	40 cm	48 cm	48 cm	48 cm	48 cm
L	Width of re-entrant for storage (=2 ϕ)	8 cm	10 cm	12 cm	12 cm	12 cm	12 cm
ϕ	Diameter of mooring eye	40 mm	50 mm	60 mm	60 mm	60 mm	60 mm
	Mass of incorporated steel (incl. Scrap Chain and mooring eye)	50 kg	100 kg	300 kg	500 kg	800 kg	1400 kg
P	Weight of sinker in water	2500 N	4000 N	6500 N	13000 N	26500 N	39000 N

D 2 SINKER WITH A CIRCULAR BASE

This is more difficult to produce, but suitable for fast currents site

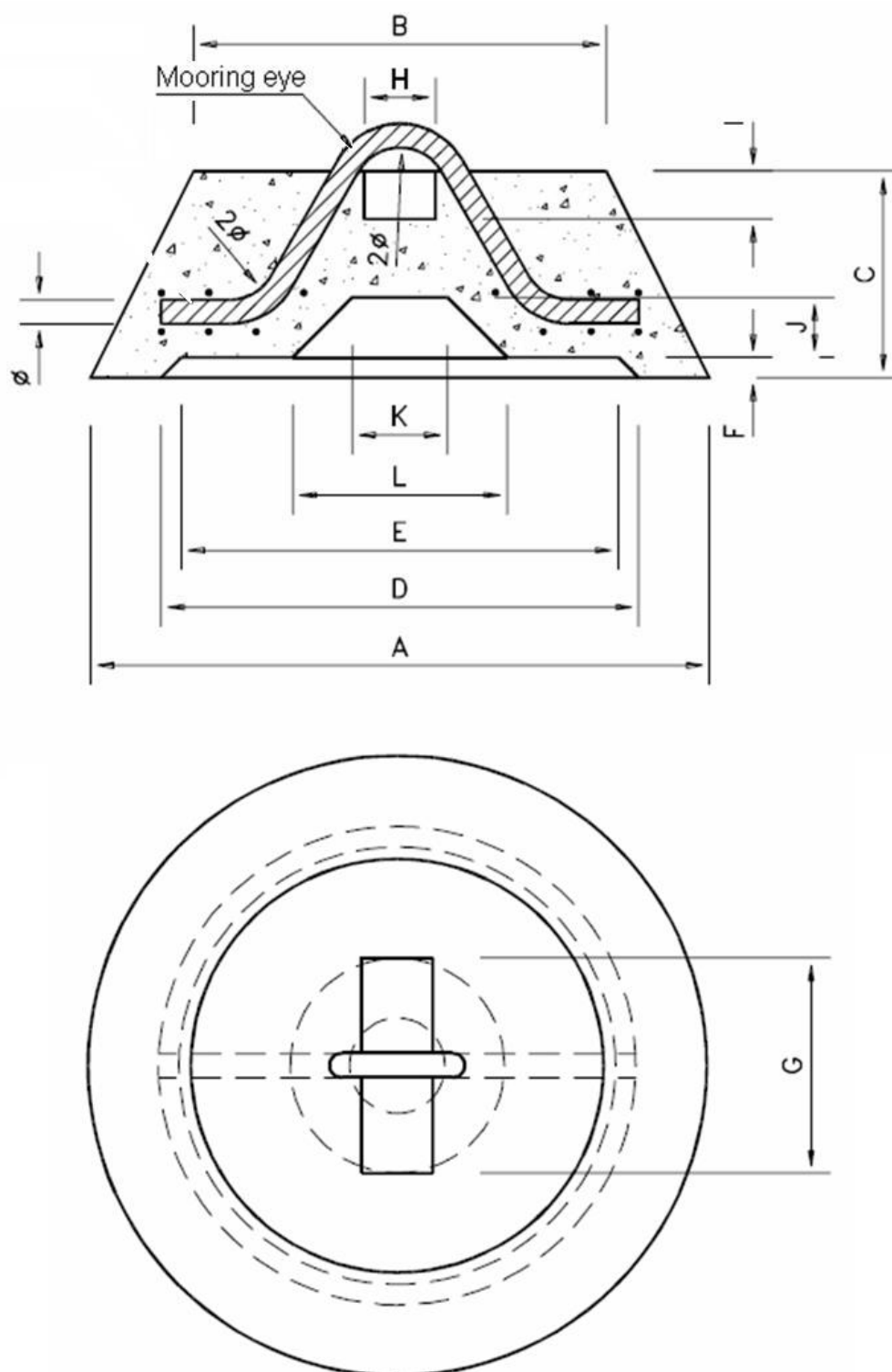


Figure 41 Circular concrete sinker

Table 5 Concrete sinker dimensions

M	Mass of sinker	400 kg	600 kg	1000 kg	2000kg	4000kg	6000kg
A	Base diameter	100 cm	110 cm	130 cm	160 cm	200 cm	230 cm
B	Upper diameter ($=2A/3$)	66.7 cm	73.3 cm	86.7 cm	106.7 cm	133.3 cm	153.3 cm
C	Height of sinker ($=A/3$)	33.3 cm	36.7 cm	43.3 cm	53.3 cm	66.7 cm	76.7 cm
D	Large diameter of the suction hole ($=22A/30$)	73.3 cm	80.7 cm	100.3 cm	122.3 cm	151.7 cm	173.7 cm
E	Narrow diameter of the suction hole ($=21A/30$)	70 cm	77 cm	91.7 cm	111.7 cm	138.3 cm	158.3 cm
F	Height of the suction hole ($=A/30$)	3.3 cm	3.7 cm	4.3 cm	5.3 cm	6.7 cm	7.7 cm
G	Length of re-entrant for shackle ($=9\phi$)	36 cm	36 cm	45 cm	54 cm	54 cm	54 cm
H	Width of re-entrant for shackle ($=3 \phi$)	12 cm	12 cm	15 cm	18 cm	18 cm	18 cm
I	Depth of re-entrant for shackle ($=2 \phi$)	8 cm	8 cm	10 cm	12 cm	12 cm	12 cm
J	Height of re-entrant for storage ($=2.5 \phi$)	10 cm	10 cm	12.5 cm	15 cm	15 cm	15 cm
K	Upper diameter of re-entrant for storage	20 cm	20 cm	20 cm	20 cm	20 cm	20 cm
L	Lower dia. of re-entrant for storage ($=K+2J$)	40 cm	40 cm	45 cm	50 cm	50 cm	50 cm
	Mooring eye diameter	40 mm	40 mm	50 mm	60 mm	60 mm	60 mm
	Mass of incorporated steel (incl. Scrap Chain and mooring eye)	50 kg	150 kg	250 kg	600 kg	1200 kg	1600 kg
P	Weight of sinker in water	2500 N	4000 N	6500 N	13000 N	26500 N	39000 N

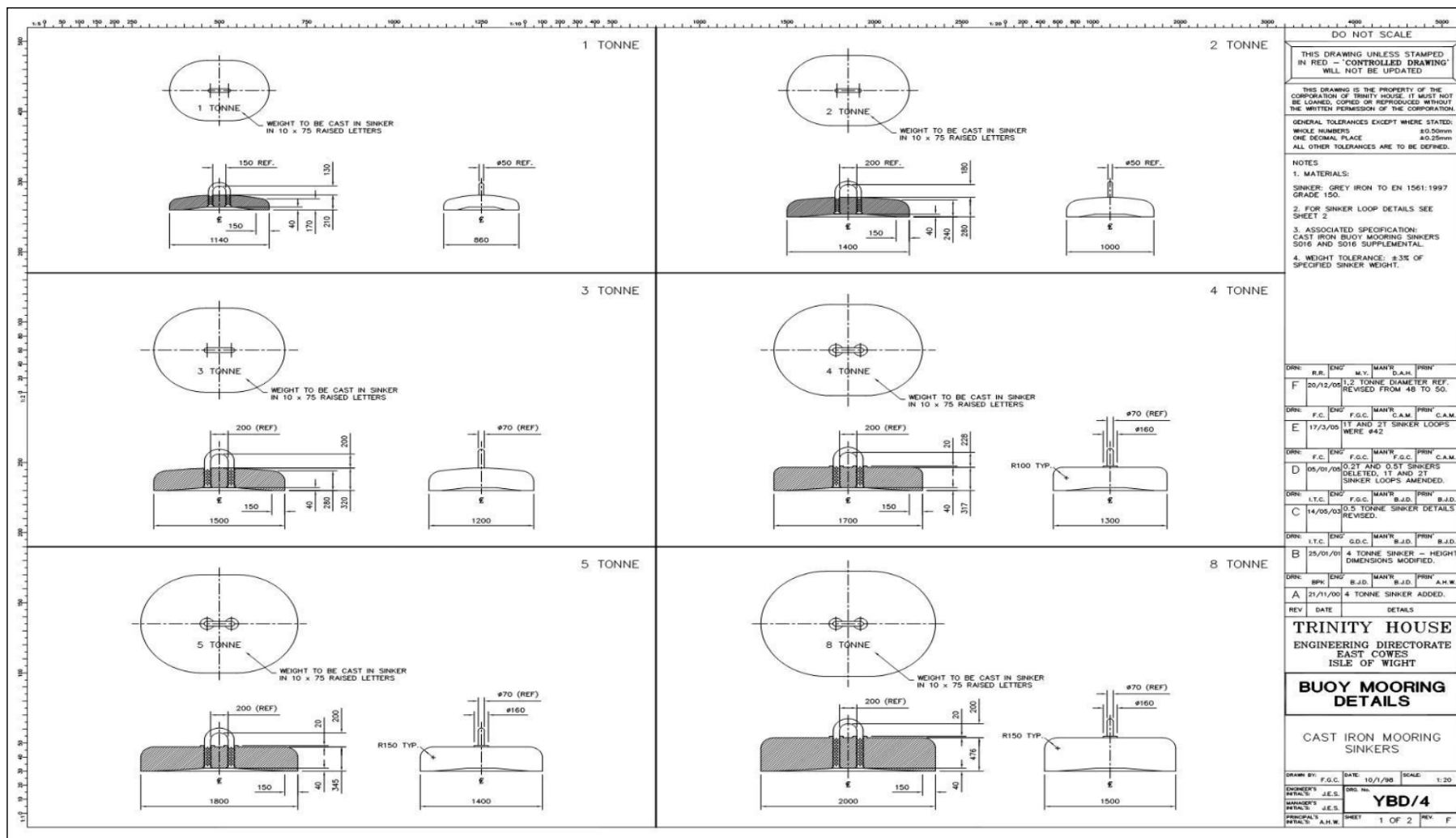


Figure 42 Cast iron sinkers

ANNEX E DETAILS OF CANADIAN COAST GUARD'S ROPE MOORING SYSTEM

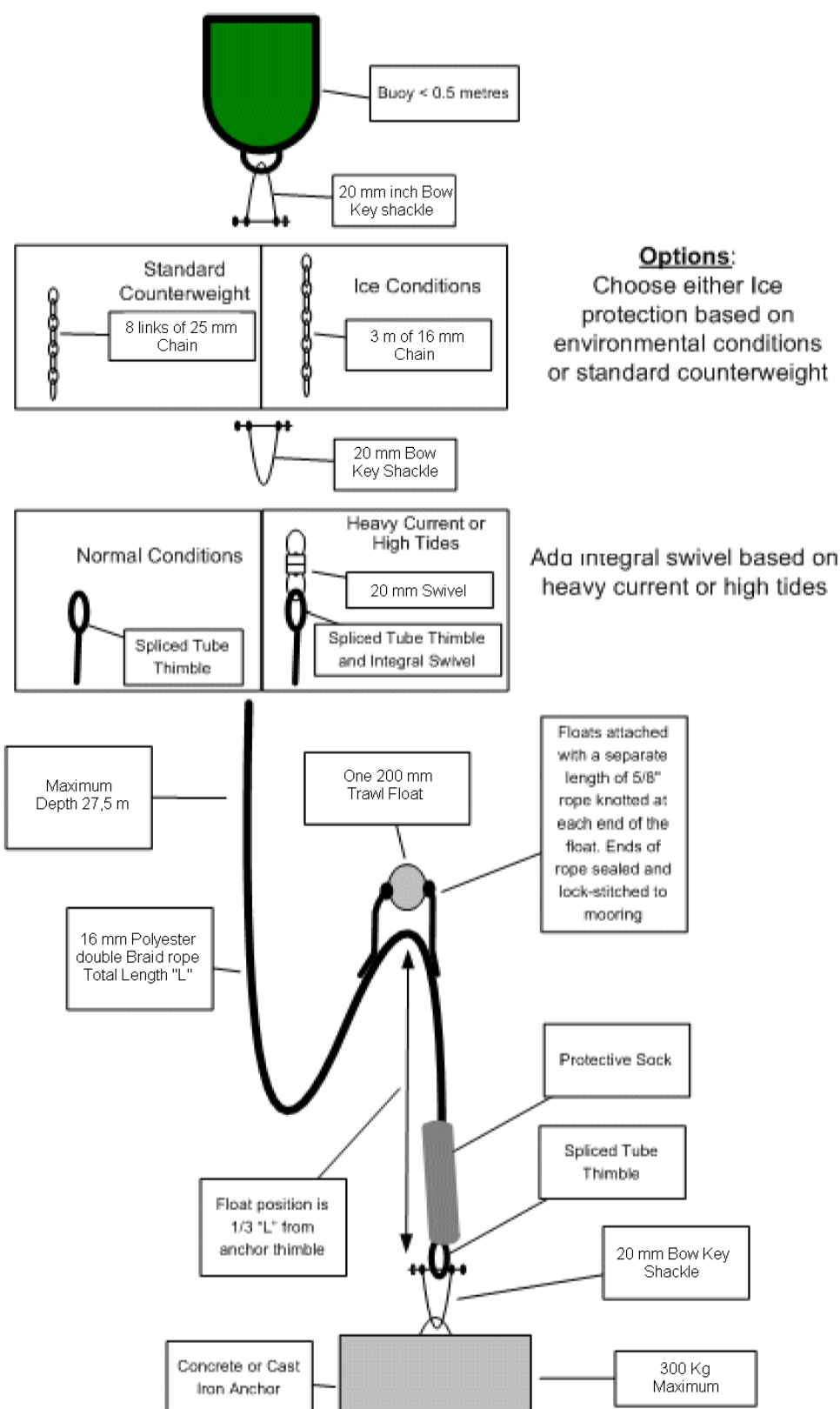


Figure 43 Canadian Coastguard rope moorings for 0.5 m buoys